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TELEGRAPHIC SYSTEMS
AND OTHER NOTES.

BY

ARTHUR CROTCH,

SILVER MEDALLIST AND HONOURSMAN IN TELEGRAPHY, AND HONOURSMAN IN
TELEPHONY, CITY AND GUILDS OF LONDON INSTITUTE; SOME TIME
LECTURER ON THESE SUBJECTS AT THE MUNICIPAL
TECHNICAL SCHOOLS, NORWICH.

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CONTENTS.

CHAPTER I.

Batteries—Primary and Secondary.

PAGES

Daniell Cell—Siemens and Halske's Cell—Minotto Cell—Callaud Cell—Meidinger Cell—Leclanché Cell—Dry Cell—Fuller's Bichromate Cell—Secondary Cells, ... 1-15

CHAPTER II.

Universal Battery Working.

Use of Secondary Batteries—Connections of Apparatus, Single Needle, Double Sounder, Single Current with Relay, Double Current, ... 16-32

CHAPTER III.

Duplex Telegraphy.

DIFFERENTIAL DUPLEX—Compensation Circuit, Rheostat—Compensation Circuit, Capacity—Differential Galvanometer, Balancing—Standard Polarized Relay—DOUBLE-CURRENT DUPLEX—BRIDGE DUPLEX—Magnetic Bridge—Comparison of Bridge and Differential Plans, ... 33-57

CHAPTER IV.

Diplex and Quadruplex Telegraphy.

DIPLEX—Non-polarized Relay—Short-circuiting at Keys—Local Circuit of B Relay—Relaying Sounder—Decrement Plan—Diplex Diagram—QUADRUPLEX—Combinations of Keys at each Station—Actual Joining-up of Quadruplex—Standard Arrangement—Simplification of B Local Circuit—Universal Working—Automatic Working on A Side—Additional Increment for Automatic Working—Decrement Working, 58-80

CHAPTER V.

Automatic Telegraphy.

PAGES

Perforator—Pneumatic Perforator—Creed's Keyboard Perforator—Kotyra Keyboard—Transmitter—Receiver—Shunted Condenser—Creed Receiving Perforator—The Murray-Creed Receiver or Printer—Automatic Set—Duplexing, . 81-103

CHAPTER VI.

Multiplex Telegraphy.

Synchronism and Isochronism—Distributor—Motor and Reed—Correcting Currents—Duplex Multiplex, ... 104-113

CHAPTER VII.

The Hughes Type-Printing Instrument.

Electrical Action—Keyboard—Key Pins and Pin Plate—Chariot—Type-wheel Axle—Printing Axle—Letters and Figures—Zero Adjusting Lever—Governor—General—Duplex, 114-131

CHAPTER VIII.

The Baudot System.

General—Sender—Receiver—Printing Mechanism—Distributor—Connections of an Arm—Synchronism—Diagram of Connections, ... 132-149

CHAPTER IX.

The Murray Type-Printing Telegraph.

Perforator — Murray Alphabet — Transmitter — Motor and Transmitting Vibrator—Receiving Apparatus—Receiving Vibrator—Local Relays—Recorder—Concerted Action of Receiving Apparatus—Governing—Printer—Letters and Figures—Duplexing, ... 150-170

CHAPTER X.

Test and Battery Boxes.

Screw-terminal Type of Board—Test-hole and U-link Board—Test-box Detectors—Switch-spring Test-board—Instrument-room Cabinet—Table Cases, ... 171-180

CHAPTER XI.

Circuit Concentration, &c.

PAGES

Concentrator Switches—Night and Sunday Concentration—Equalising Resistances—Mixed Up and Down Circuits—Mixed Single- and Double-current Circuits—Metropolitan Intercommunication System—Central Battery System—Central Battery Duplex, ... 181-194

CHAPTER XII.

Repeaters.

Evolution of Repeater—Simple Repeater—Duplex Repeater—Double-current Repeater—Hughes Repeaters—Neutralisation of Cable Discharge—Hughes Duplex Repeaters—Fast Speed Repeaters—Forked News Repeater—Quadruplex Repeaters—Pole-changer—Diplex Repeater—Quadruplex Repeater—Forked Quadruplex Repeater—Split Quadruplex Repeater—Quadruplex, A Side Relayed—Sounder Silencer—Test and Battery-box Connections, . 195-234

CHAPTER XIII.

Submarine Telegraphy.

Reflecting or Mirror Galvanometer—Siphon Recorder—Received Signals, Curbing—Automatic Working—Perforator—Automatic Curb Transmitter—Connections—Duplexing—Repeating, ... 235-252

CHAPTER XIV.

Wireless Telegraphy.

General—Oscillator—Coherer—Lodge-Muirhead Coherer—Magnetic Detector—Simple Installation—Oscillation Transformer—Syntony—Use of the Earth—Poulsen's Arc—Skegness-Hunstanton Installation, ... 253-263

Index, ... 265
List of Diagrams of Connections, ... 268

131E 45

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"ELEMENTARY TELEGRAPHY AND TELEPHONY."
"TELEGRAPH SECONDARY CELL INSTALLATIONS."
"THE HUGHES AND BAUDOT TELEGRAPHS."

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PREFACE.

In the following pages I have endeavoured to give a plain and concise description of the main systems in use in practical telegraphy. The latter limiting condition naturally rules out many ingenious plans and much delicate apparatus, which, though of great merit and giving, in some cases, very high speeds, have not succeeded in proving their adaptability to working conditions.

The Hughes instrument is a great favourite in Continental telegraphy, but it has not found favour to any great extent in England: the Wheatstone automatic is a distinct feature of British telegraphy, whilst France is the home of the Bandot system. The Murray is now utilised in many countries, and successful trials have been made over some long circuits. The system is essentially one for long-distance working, and ~~it~~ is not easy to predict the extent of its future development.

An acquaintance with the simpler instruments used in ordinary Morse working, such as keys, galvanometers, &c., is assumed.

I have to acknowledge the courtesy of Messrs. Muirhead & Co. in lending blocks for the Chapter on Submarine Telegraphy, and of The India-rubber and Gutta-percha Co. for Figs. 60, 147, 168, and 183.

A. C.

Engineer-in-Chief's Department,
G.P.O., London, E.C.,
February, 1908.

CONTENTS.

CHAPTER I.

Batteries—Primary and Secondary.

PAGES

Daniell Cell—Siemens and Halske's Cell—Minotto Cell—Callaud Cell—Meidinger Cell—Leclanché Cell—Dry Cell—Fuller's Bichromate Cell—Secondary Cells, ... 1-15

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CHAPTER V.

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PAGES

Perforator—Pneumatic Perforator—Creed's Keyboard Perforator—Kotyra Keyboard—Transmitter—Receiver—Shunted Condenser—Creed Receiving Perforator—The Murray-Creed Receiver or Printer—Automatic Set—Duplexing, . 81-103

CHAPTER VI.

Multiplex Telegraphy.

Synchronism and Isochronism—Distributor—Motor and Reed—Correcting Currents—Duplex Multiplex, ... 104-113

CHAPTER VII.

The Hughes Type-Printing Instrument.

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CHAPTER VIII.

The Baudot System.

General—Sender—Receiver—Printing Mechanism—Distributor—Connections of an Arm—Synchronism—Diagram of Connections, ... 132-149

CHAPTER IX.

The Murray Type-Printing Telegraph.

Perforator—Murray Alphabet—Transmitter—Motor and Transmitting Vibrator—Receiving Apparatus—Receiving Vibrator—Local Relays—Recorder—Concerted Action of Receiving Apparatus—Governing—Printer—Letters and Figures—Duplexing, ... 150-170

CHAPTER X.

Test and Battery Boxes.

Screw-terminal Type of Board—Test-hole and U-link Board—Test-box Detectors—Switch-spring Test-board—Instrument-room Cabinet—Table Cases, ... 171-180

CHAPTER XI.

Circuit Concentration, &c.

PAGES

Concentrator Switches—Night and Sunday Concentration—Equalising Resistances—Mixed Up and Down Circuits—Mixed Single- and Double-current Circuits—METROPOLITAN INTERCOMMUNICATION SYSTEM—CENTRAL BATTERY SYSTEM—Central Battery Duplex, ... 181-194

CHAPTER XII.

Repeaters.

Evolution of Repeater—Simple Repeater—Duplex Repeater—Double-current Repeater—HUGHES Repeaters—Neutralisation of Cable Discharge—Hughes Duplex Repeaters—FAST SPEED REPEATERS—Forked News Repeater—QUADRUPLEX REPEATERS—Pole-changer—Diplex Repeater—Quadruplex Repeater—Forked Quadruplex Repeater—Split Quadruplex Repeater—Quadruplex, A Side Relayed—Sounder Silencer—Test and Battery-box Connections, . 195-234

CHAPTER XIII.

Submarine Telegraphy.

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CHAPTER XIV.

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General—Oscillator—Coherer—Lodge-Muirhead Coherer—Magnetic Detector—Simple Installation—Oscillation Transformer—Syntony—Use of the Earth—Poulsen's Arc—Skegness-Hunstanton Installation, ... 253-263

INDEX, ... 265

LIST OF DIAGRAMS OF CONNECTIONS, ... 268

LIST OF ILLUSTRATIONS.

FIG. PAGE
1. Daniell cell, 2
2. Daniell battery (trough form), 3
3. Siemens and Halske's cell, 4
4. Minotto cell, 5
5. Callaud cell, 5
6. Meidinger cell, 6
7. Lelanché cell (ordinary form), 8
8. ,, with circular zinc, 8
9. Six-block agglomerate Leclanché, 8
10. Hellesen's dry cell, 9
11. Bichromate cell, 9
12. Hart accumulator plates, 12
13. E.P.S. plates, 13
14. Seven-plate secondary cell, 14
15. Arrangement of voltages, 18
16. Single needle: ordinary, with primary batteries, 19
17. ,, universal batteries, up station, 19
18. ,, ,, ,, down station, 21
19. Double sounder, 22
20. ,, universal batteries, up station, 23
21. ,, ,, ,, down station, 24
22. Single current, with relay, 25
23. ,, ,, universal batteries, up station, 26
24. ,, ,, ,, ,, down station, 27
25. ,, ,, ,, ,, intermediate station, 27
26. Double current, 28
27. ,, universal batteries, up station, 29
28. ,, ,, ,, down station, 30
29. ,, ,, ,, intermediate station (*a*), 31
30. ,, ,, ,, ,, ,, (*b*), 31
31. Duplex: differential winding, 34
32. ,, principle of, 35
33. ,, theoretical arrrangement of circuit, 37
34. Diagram of rheostat, 39
35. Triple condenser, 39

FIG. PAGE
36. Standard polarized relay, ... 40
37. ,, ,, plan, ... 41
38. ,, ,, cores and armatures, ... 43
39. Single current: duplex or single, ... 44
40. ,, skeleton duplex, ... 44
41. ,, duplex: both keys depressed, ... 45
42. Double-current duplex: both keys at rest, ... 46
43. ,, ,, one key up, one down, ... 47
44. ,, duplex or single, ... 48
45. ,, ,, ,, universal batteries, up station, 49
46. Bridge duplex: principle, ... 50
47. ,, details of example, ... 51
48. ,, potentials at various points, ... 52
49. ,, ,, ,, ... 52
50. ,, ,, ,, ... 53
51. ,, details of further example, ... 54
52. ,, currents in various branches, ... 55
53. ,, ,, ,, ... 55
54. ,, ,, ,, ... 55
55. Double current: bridge duplex or single, ... 57
56. Principle of diplex, ... 59
57. Standard non-polarized relay, ... 60
58. ,, ,, ,, plan, ... 61
59. ,, ,, ,, cores and armatures, ... 61
60. Relaying sounder, ... 64
61. Theoretical diplex circuit, ... 65
62. Diplex or single, ... 66
63. Diplex: inter-action of A and B keys, ... 67
64. Quadruplex: analysis of key positions, ... 70
65. ,, ,, ,, ... 70
66. ,, ,, ,, ... 71
67. ,, ,, ,, ... 71
68. ,, skeleton of circuit, ... 73
69. ,, old form, ... 74
70. ,, standard form, ... 75
71. ,, ,, secondaries, ... 76
72. ,, Wheatstone A side, ... 78
73. ,, ,, ,, secondaries, ... 79
74. ,, incrementing voltages, ... 80
75. Connections of 9-terminal, 2-position switch, ... 80
76. Wheatstone perforator, ... 82
77. ,, ,, details, ... 84
78. ,, ,, ,, ... 85

FIG.		PAGE
79.	Pneumatic perforator,	86
80.	,, ,,	86
81.	,, ,, details,	87
82.	Wheatstone transmitter,	90
83.	,, ,, *internal arrangements*,	91
84.	Details of Wheatstone slip,	92
85.	Wheatstone receiver,	94
86.	Shape of signals,	96
87.	Shunted condenser,	97
88.	Automatic,	98
89.	,, *secondaries*,	99
90.	,, duplex or single,	100
91.	,, ,, ,, secondaries,	101
92.	,, bridge duplex or single,	102
93.	Multiplex principle,	104
94.	,, details of distributor,	107
95.	,, connection of arms,	107
96.	,, motor and reed,	108
97.	,, hexode diagram,	110
98.	Effect of retardation,	112
99.	Duplex multiplex,	113
100.	Hughes instrument,	115
101.	,, ,, front elevation,	116
102.	,, ,, plan,	117
103.	,, ,, type-wheel, &c.,	120
104.	,, ,, correcting-wheel, &c.,	120
105.	,, ,, printing axle,	122
106.	,, ,, detent arm, &c.,	123
107.	,, ,, governor, &c.,	126
108.	,, ,, diagram,	127
109.	Hughes: duplex (bridge) or single,	128
110.	,, ,, (differential) or single,	129
111.	,, ,, skeleton,	130
112.	Baudot: principle of system,	132
113.	,, alphabet, &c.,	135
114.	,, sender,	136
115.	,, ,, *details*,	137
116.	,, receiver,	138
117.	,, ,, details,	139
118.	,, ,, ,,	140
119.	,, ,, ,,	141
120.	,, ,, printing mechanism,	143
121.	,, distributor, front view,	144

FIG. PAGE
122. Baudot distributor, side view, ... 145
123. ,, ,, arrangement of segments, ... 146
124. ,, connections of an arm, ... 147
125. ,, tetrode working, diagram, ... 148
126. Murray perforator, ... 150
127. ,, ,, details, ... 151
128. ,, ,, ,, ... 151
129. ,, alphabet, ... 153
130. ,, transmitter: front, ... 154
131. ,, ,, back, ... 155
132. ,, ,, details, ... 156
133. ,, transmitting vibrator, ... 157
134. ,, ,, ,, and motor, ... 158
135. ,, receiving vibrator, ... 158
136. ,, recorder, ... 159
137. ,, ,, details, ... 160
138. ,, diagram of receiving circuit, ... 161
139. ,, details of slip, ... 162
140. ,, printer: front, ... 164
141. ,, ,, back, ... 164
142. ,, ,, details, ... 165
143. ,, ,, ,, ... 166
144. ,, diagram of system, ... 169
145. Test and battery box: screw-terminal type, ... 172
146. ,, ,, test-hole and U-link type, . . . 173
147. Test-box detector, ... 174
148. Test-board: switch-spring type, ... 175
149. ,, ,, ,, details, ... 177
150. Instrument-room cabinet, ... 178
151. Table case, ... 179
152. Concentrator switch, ... 181
153. ,, ,, connections, ... 182
154. ,, mixed single- and double-current circuits, . . 185
155. Metropolitan intercommunication: switch connection of a circuit, ... 187
156. ,, ,, skeleton of above, &c., . 187
157. ,, ,, cord circuit, ... 188
158. ,, ,, ,, switch "speaking," 190
159. ,, ,, two offices "through," . 190
160. ,, ,, "clearing," 191
161. Central battery working, ... 192
162. ,, ,, concentrator, ... 192
163. ,, duplex or single, ... 193

FIG.		PAGE
164.	Evolution of repeater,	196
165.	Simple repeater,	197
166.	Duplexing of repeater,	199
167.	,, ,,	200
168.	Automatic (electro-magnetic) switch,	201
169.	Double-current repeater: principle,	202
170.	Hughes repeater: single,	204
171.	,, ,, duplex or single,	206
172.	,, ,, ,, plan,	207
173.	,, ,, ,, diagram,	208
174.	,, ,, single,	209
175.	,, ,, duplex or single,	210
176.	Fast speed repeater: duplex or single,	212
177.	,, ,, skeleton of connections,	213
178.	,, ,, duplex or single: diagram,	214
179.	Forked news repeater,	216
180.	,, ,, plan,	217
181.	,, ,, diagram,	218
182.	,, ,, ,, (skeleton),	219
183.	Pole reverser,	220
184.	Incrementer,	220
185.	To repeat diplex (old plan),	221
186.	,, ,, (present plan),	221
187.	Repeater: quadruplex or single,	222
188.	,, ,, ,, *(skeleton)*,	223
189.	Forked quadruplex repeater,	224
190.	Split quadruplex repeater,	226
191.	Quadruplex: A side relayed,	227
192.	,, ,, (skeleton),	228
193.	Sounder silencer,	229
194.	,, ,, details,	230
195.	,, ,, connections,	232
196.	Repeaters: test and battery-box connections,	233
197.	,, ,, ,, secondaries,	234
198.	Mirror galvanometer,	237
199.	Cable sending keys,	237
200.	Siphon recorder,	238
201.	,, ,, bridge-piece,	239
202.	,, ,, diagram,	240
203.	Submarine automatic slip,	241
204.	Automatic curb transmitter,	242
205.	,, ,, details,	243
206.	,, ,, ,,	243

FIG. PAGE
207. Automatic curb transmitter, details, ... 244
208. ,, ,, ,, ... 245
209. ,, ,, ,, ... 24[illegible]
210. Cable working, diagram, ... 247
211. Muirhead's artificial circuit, ... 248
212. Cable working, duplex diagram, ... 249
213. Principle of Brown's cable repeater, ... 250
214. Muirhead's cable repeater, ... 251
215. Coherer, ... 254
216. Lodge-Muirhead coherer, ... 255
217. Electro-magnetic detector, ... 256
218. Simple wireless installation, ... 256
219. Tuned ,, ... 258
220. Hunstanton-Skegness installation: aerial, ... 261
221. ,, ,, receiving diagram, . . 262
222. ,, ,, sending ,, . . 263

TELEGRAPHIC SYSTEMS.

CHAPTER I.

BATTERIES: PRIMARY AND SECONDARY.

A BATTERY suitable for ordinary telegraphic work must be capable of supplying a constant current, of no great strength, for long periods—that is, the chemical action must be steady rather than powerful. It must also be able to run for considerable lengths of time with a minimum of attention. For such purposes, the cell invented by Daniell is practically without a competitor.

Daniell Cell.—Zinc is used as the positive electrode in practically all primary cells, and carbon, copper, or platinum generally as the negative. In all, too, the same trouble is experienced—viz., the getting rid of the liberated hydrogen. With a plate of copper and one of zinc in dilute sulphuric acid the "sulphion" (SO_4) of the latter combines with the zinc, forming the sulphate of that metal, and the hydrogen of the acid is set free. This appears at the copper plate and adheres thereto, partially insulating it and also setting up an opposing E.M.F., or *polarizing* the cell. Daniell employed all these constituents of the simple cell, but divided it into two parts by a porous division—a diaphragm of unglazed earthenware. In one side was placed the zinc and exciting solution, and in the other the copper plate and a second fluid or depolarizer, a solution of copper sulphate. The porous division acts as a mechanical separator of the two liquids, but allows the electrical action to go on through it. The hydrogen freed at the copper plate decomposes the copper sulphate, re-forming sulphuric acid and liberating metallic copper, which is thrown down upon the plate. By this means polarization is prevented. The chemical action is indicated as follows:—

Before contact—

$$Zn,\ H_2SO_4 \quad \| \quad CuSO_4,\ CuSO_4,\ Cu.$$

After contact—

$$ZnSO_4,\ H_2SO_4 \quad \| \quad CuSO_4,\ CuCu.$$

When pure zinc is used the acid acts on it only when the circuit is closed—*i.e.*, when the cell is at work. With impure zinc, which is invariably employed, the action also goes on when the cell is idle. This is termed "local action," and is obviously wasteful. In practice this is generally prevented by "amalgamating" the zinc plate—that is, by covering the plate with a thin layer of mercury—the latter having the peculiar property of entering into most intimate relation with many metals and forming alloys or amalgams. In the Daniell cell, however, the zinc is not amalgamated, but a solution of zinc sulphate is used. In starting a cell, only plain water is generally placed with the zinc. In working, both sulphuric acid and zinc sulphate are generated, the former from the copper sulphate, and the latter by its action on the zinc. If a battery be required for immediate use some zinc sulphate solution is placed with the zinc.

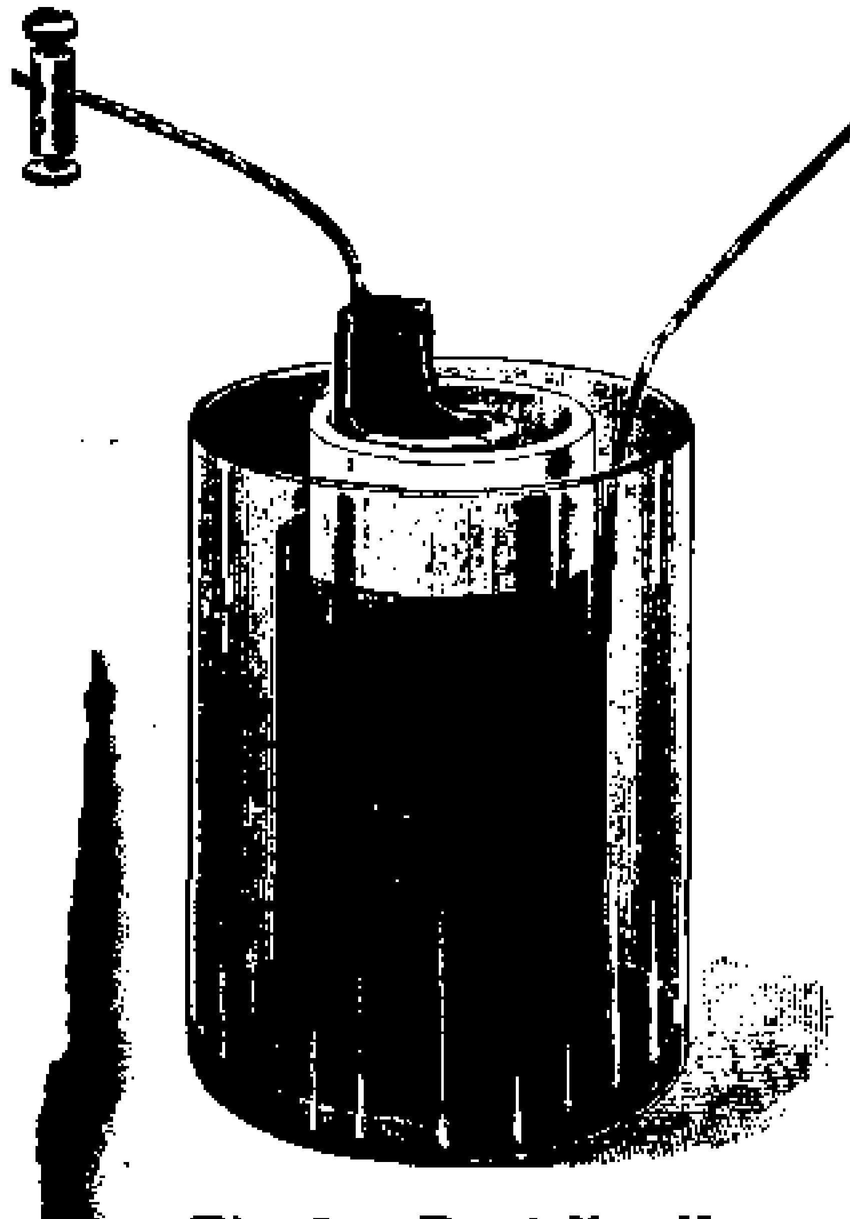


Fig. 1.—Daniell cell.

The principal characteristic of the Daniell cell is its great constancy. It is best employed in continuous work, so as to take from it all that it is capable of giving as useful work. If allowed to stand idle, great waste occurs. The solutions mingle through the porous partition, and copper is deposited on the zinc plate. A constant supply of copper sulphate crystals should be maintained, and the solution in the zinc compartment should not be allowed to become too concentrated. When this takes place fresh water should be substituted for some of the liquid.

A simple form of the cell is illustrated in Fig. 1, where the porous division is in the shape of a cylindrical "porous pot," the copper and zinc plates—both also cylindrical—being respectively outside and inside of this, and the whole contained in a glass jar. The E.M.F. of the cell is just over 1 volt (1·07), being, of course, irrespective of the size of the cell, and depending entirely upon the materials used. The internal resistance of the quart size is from 3 to 5 ohms.

The form of Daniell battery in common use for telegraph purposes is the "trough"—an assemblage of five or ten cells in a wooden box, as in Fig. 2. This is constructed in the following manner:—A box of teak is fitted with slate partitions in suitable grooves to form the required number of cells. To render the whole watertight, the partitions, bottom and sides, are then coated with marine glue, a compound of shellac, caoutchouc, and naphtha. To prevent the adhesion of the electrodes, &c., to this, glass plates are laid on the walls and bottoms of the cells, and thus firmly fixed. A further division, about half an inch in height, is placed in each cell, and this serves to retain in position a flat porous cell, in which the copper plate is contained. Outside the porous vessel is a stout zinc plate. The zinc and copper plates are supplied in pairs—that is, already connected together by a copper strap riveted into the copper plate, and having the zinc cast on the other end. Each pair is then bent over, so that the copper enters the porous compartment of one cell and the zinc the outer portion of the next cell. The terminal plates are necessarily single. The zinc plate is of considerable thickness, as this is gradually consumed by the action of the battery, whereas the copper is continually growing in thickness by the

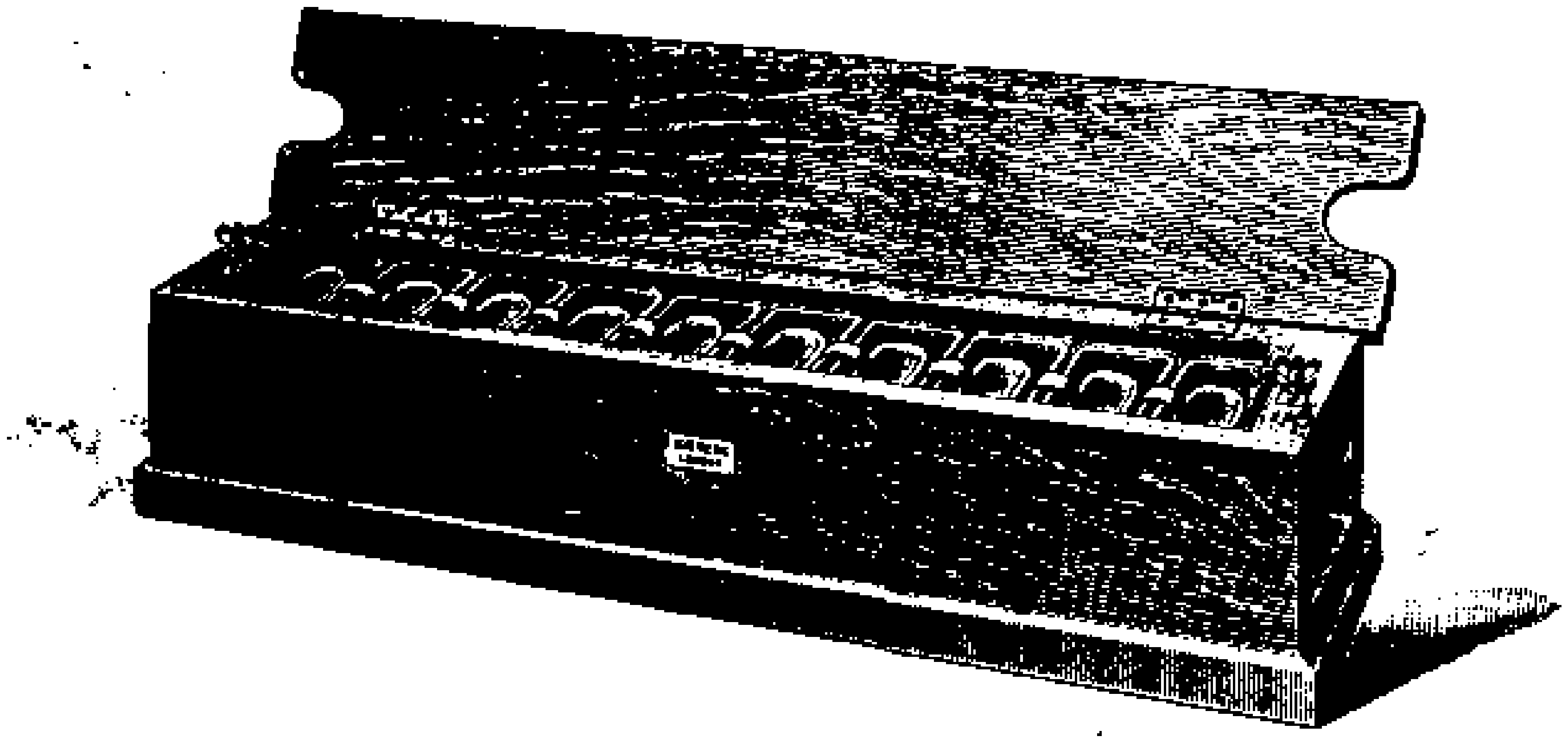


Fig. 2.—Daniell battery—Trough form.

deposit of metal thrown down upon it. It is, therefore, originally very thin.

These batteries were originally made up in two sizes (of cell), "large" and "small." The former have zinc and copper plates, 4½ by 2½ and 4½ by 4½ inches respectively, and the latter 3¼ by 2 and 2¼ by 3¼ inches. New issues will consist of the large size only. The resistance per cell of the large is about 4 or 5 ohms, and of the small 7 or 8 ohms.

In charging the battery, a quantity of crystals of copper sulphate is placed in the porous cells, the latter and the zinc compartments being filled up with soft water. It is advisable to allow an interval between the placing of the water in the copper compartment and the filling up of the zinc side, as the water will then soak through and displace any air from the pores of the porous vessel.

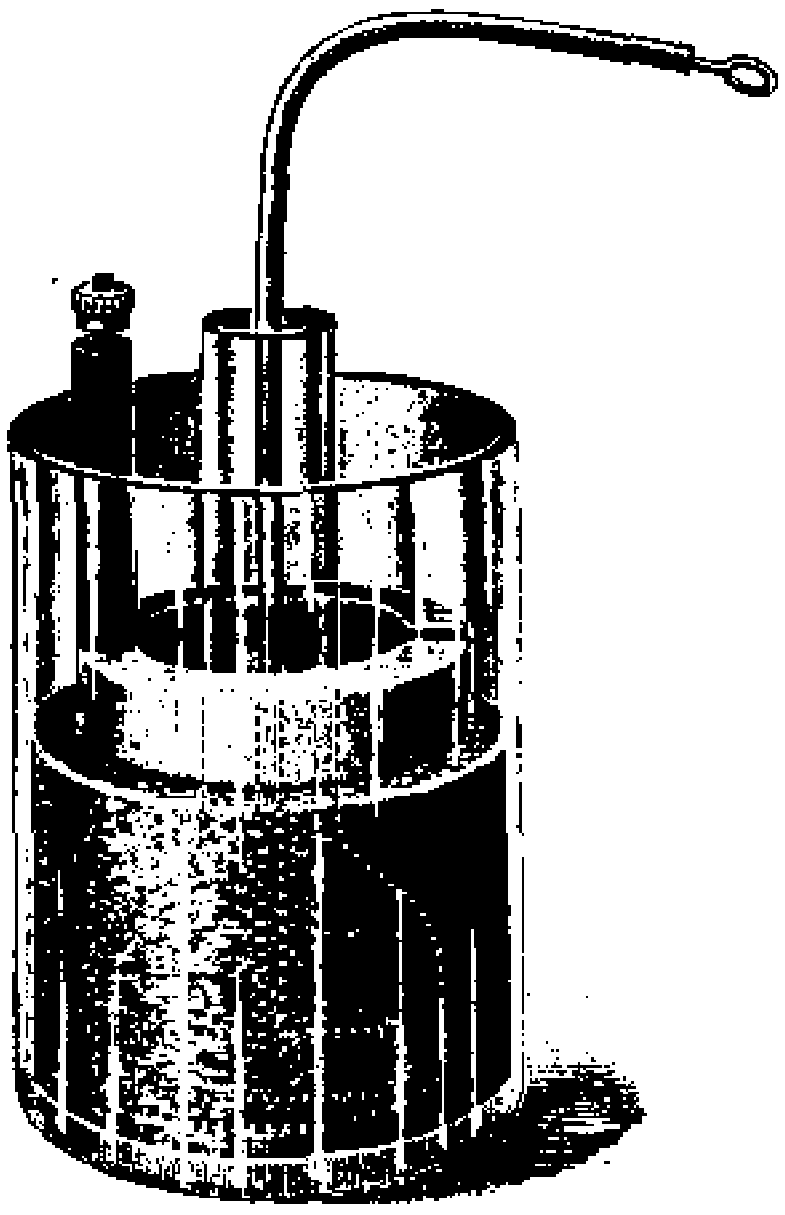


Fig. 3.—Siemens and Halske's cell.

Siemens and Halske's Cell.—This, shown in Fig. 3, is a German form of Daniell, and has an additional porous diaphragm by which the penetration of the sulphate of copper to the zinc is retarded. On the bottom of a glass containing jar is placed a porous vessel, in shape a bell or inverted cup, as can be seen in the figure by the dotted lines. Into the upper portion of this a glass tube is cemented, so that the whole forms a cylinder, much enlarged at the base. This serves to contain the copper sulphate crystals and solution and the negative electrode, a broad strip of copper bent into the shape of a cross, standing edgewise on the base of the cell. From this strip a gutta-percha covered copper wire is taken up the glass tube to serve as the positive pole. Over the porous cup a mass of paper pulp is placed so as to fill the jar to about half its height, and on the top of this a heavy ring of amalgamated zinc with stalk and connection screw. The inner vessel being charged with copper sulphate crystals and water, the external jar is filled up with water so as just to cover the zinc ring. The two electrodes, with their surrounding fluids, are thus separated, not only by the porous cup, but also by the mass of paper pulp. The resistance, of course, is considerably increased; in an ordinary quart-sized jar it ranges from 10 to 15 ohms.

Minotto Cell.—In this, another form of Daniell, sand or sawdust is employed instead of a porous pot (see Fig. 4). At the bottom of the outer jar a copper disc is placed, and is covered with a layer of copper sulphate crystals to a depth of about an inch and a-half. Over this is a disc of cloth, blotting-paper, or calico, and then a layer of sand or sawdust 2 or 3 inches deep. Over this another disc of cloth, blotting-paper, or calico is laid, and the whole surmounted by a zinc disc with stalk and terminal. A copper wire is connected to the copper plate, and, covered with gutta-percha, this wire is led up through the several layers and through a notch in the zinc disc out of the cell. The containing vessel is then filled up with water so as to cover the zinc. The internal resistance varies from about 10 to 20 ohms.

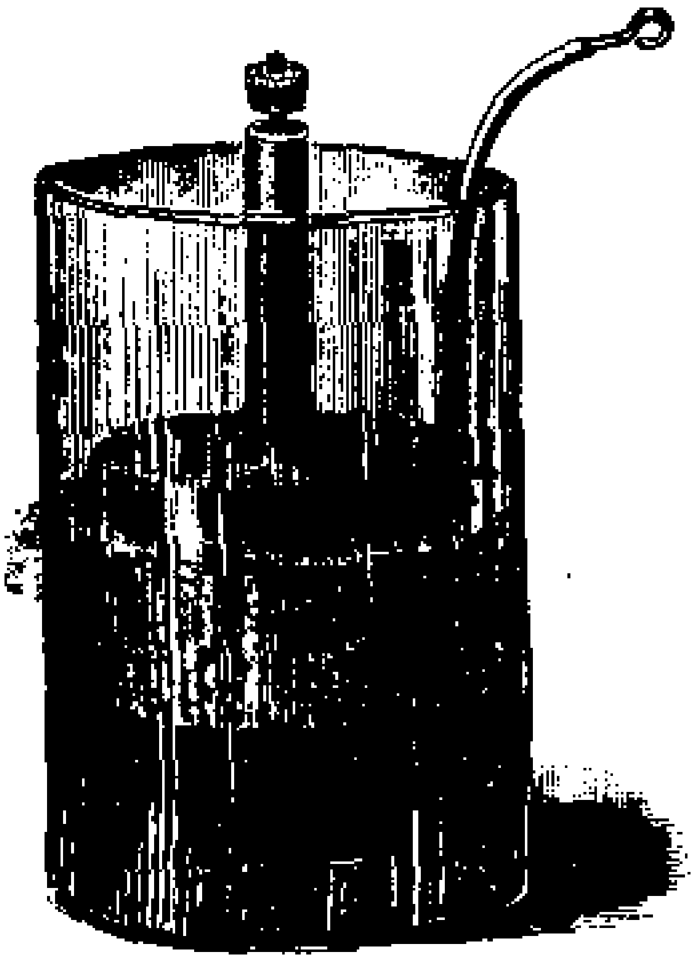


Fig. 4.—Minotto cell.

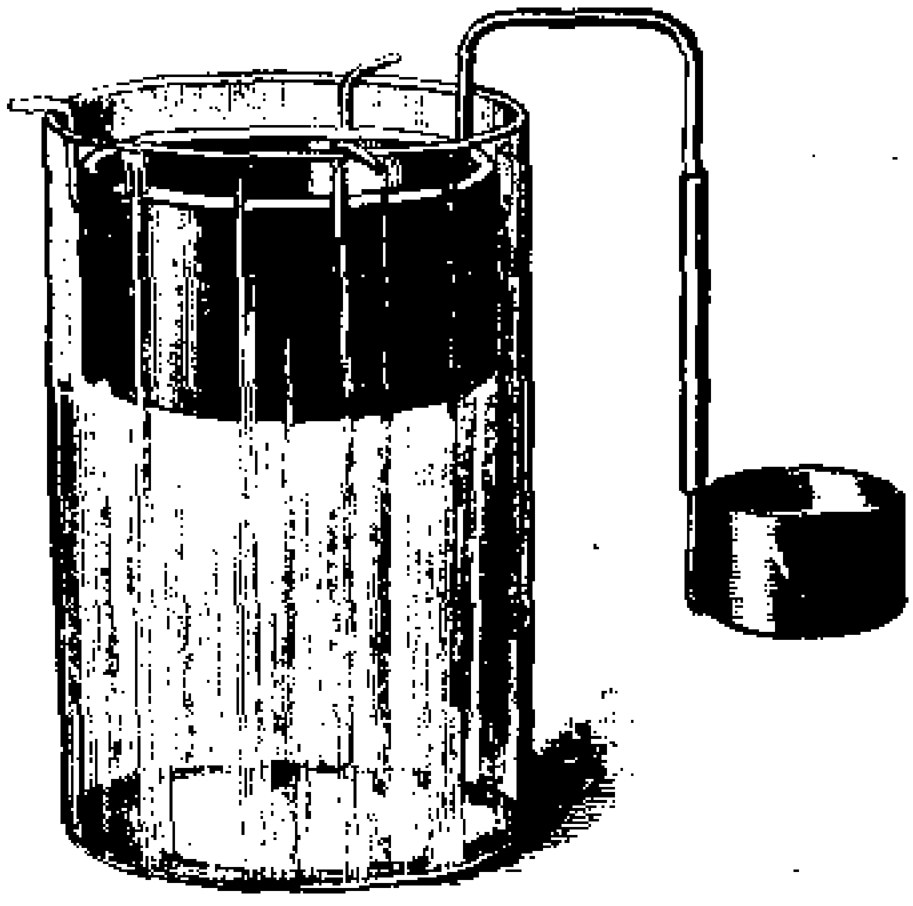


Fig. 5.—Callaud cell.

Callaud Cell.—In this, also a Daniell, no porous jar or division whatever is used, but the two liquids are prevented from mixing by the difference in their specific gravities. From this characteristic it is termed a "gravity cell." Thus the copper sulphate solution, being the heavier, keeps at the bottom of the cell, whilst the lighter sulphate of zinc remains at the top. Of course, eventually the two liquids will become mixed, but if the cell be kept perfectly immovable—an absolutely necessary condition—the action is very slow. The cell is illustrated in Fig. 5.

From the rim of the containing vessel a split ring or short cylinder of zinc is suspended by three copper hooks. The copper of the next cell, also a cylinder, is supported by this through the intermediation of the connecting insulated wire. The liquid with which the jar is filled should consist of nine-tenths water and one-tenth of a saturated solution of zinc sulphate. A saturated solution of copper sulphate is then placed at the bottom of the jar by means of a siphon, or the crystals themselves may be dropped into the liquid in sufficient quantity to cover the copper cylinder.

The resistance of the cell depends upon the degree of concentration of the solutions—varying between 2 and 4 ohms.

Meidinger Cell.—This is another form of Daniell gravity cell, no porous diaphragm being used. It consists, as shown in Fig. 6, of an outer glass jar which has a larger diameter at the top than at the base. At the bottom a glass cup is placed, and in this is the negative electrode, a sheet copper cylinder to which is connected the insulated terminal wire. The zinc, a large split cylinder, rests on the inner rim of the outer jar, and is also provided with a terminal wire. A large balloon-shaped flask rests on the outer jar, having its neck closed by a cork, through which passes a short glass tube as shown. The containing jar is charged with plain water, to which is added some magnesium sulphate (Epsom salts) in the proportion of 1 part of salts to 4 or 5 of water by weight. The flask is charged with copper sulphate crystals and water, and its cork and tube having been inserted, the flask is inverted and placed in the jar. The solution gradually leaves the flask, and displaces some of the lighter zinc sulphate. The resistance of the cell is from 2 to 6 ohms. The balloon-shaped vessel is sometimes replaced by a large plain test-tube with perforated bottom, through which the solution passes to the bottom of the cell.

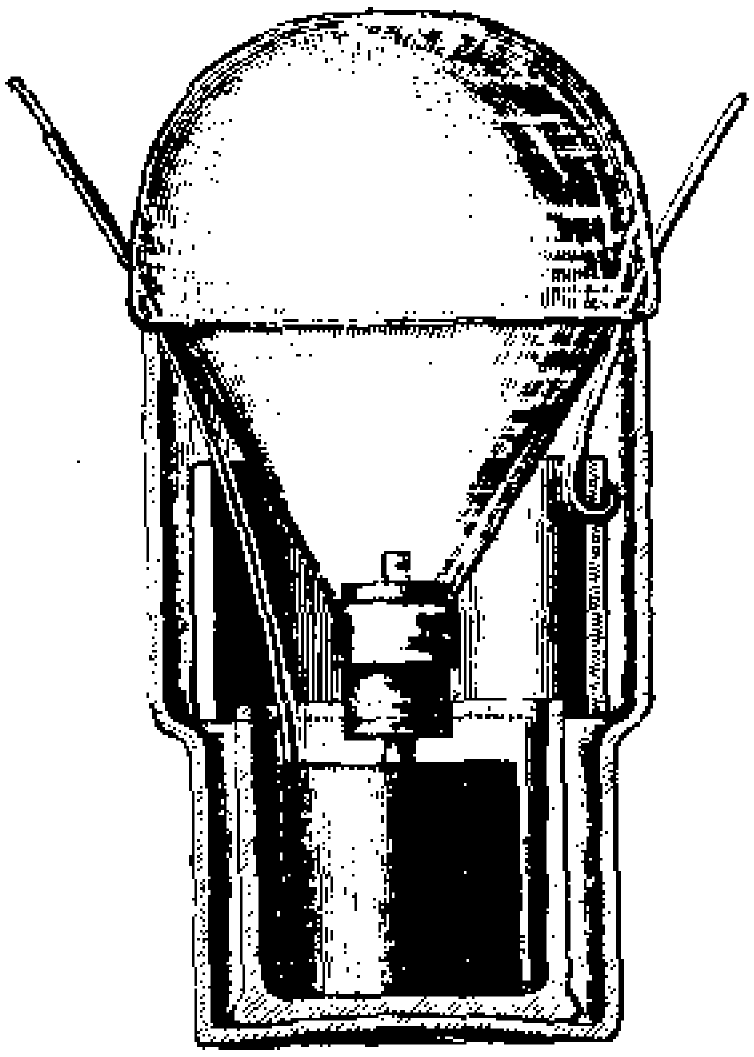


Fig. 6.—Meidinger cell.

Leclanché Cell.—Of all primary batteries, this, with its so

is the best known and the most popular.

In telegraphy it has well filled a very considerable field, where short periods of activity alternate with long periods of rest.

The active agent is a solution of ammonium chloride (sal-ammoniac), which, when the circuit is closed, attacks the zinc and forms the chloride of that metal, hydrogen again being liberated. The negative electrode is carbon, and the oxidising material peroxide of manganese. The latter, in the form of "pebble manganese"—*i.e.*, in coarse grains—is mixed with carbon also in the same state of division, and packed around the carbon electrode, the latter and the mixture being generally enclosed in a porous pot.

The constituents of ammonium chloride are nitrogen, hydrogen, and chlorine. Of these the chlorine combines with the zinc. Part of the hydrogen enters into combination with a portion of the oxygen of the manganese peroxide, forming water; whilst the nitrogen and the rest of the hydrogen are evolved as ammonia. This partially dissolves in the solution, and the rest is given off. The depolarizer is reduced to a lower oxide. This is easily seen in the following equation :—

Before contact—

$$Zn + NH_4Cl, NH_4Cl \quad \| \quad MnO_2, MnO_2 + C.$$

After contact—

$$Zn + ZnCl_2 + 2NH_3 + H_2O \quad \| \quad Mn_2O_3 + C.$$

The great advantage of the Leclanché cell is that, whilst on open circuit, no action takes place. It is, therefore, admirably fitted for intermittent work; when thus employed it is capable of standing for very long periods without attention. It cannot, however, furnish a fairly strong current for any length of time, as the manganese dioxide is only capable of taking up the hydrogen slowly. After polarizing, if it be allowed to rest, it soon recovers, and is ready for fresh work. In charging, it is preferable to make up a concentrated solution of sal-ammoniac, and fill the cell with 2 parts of this to 1 of water. The E.M.F. is about 1·5 volts.

The commonest form of the cell is shown in Fig. 7. The carbon plate, surrounded by the broken manganese and carbon, stands in a porous pot, the top of which is sealed with pitch or marine glue, a small hole being left for the escape of air or gases. To secure a good connection between the carbon plate and its terminal is very important, and somewhat difficult. It is generally obtained by casting a leaden cap on the top of the plate, and fixing the terminal in the cap. The zinc is a simple rod. The wire from the latter has to be covered with gutta-percha or other similar material to protect it from the ammonia given off by the cell. This form is used in telegraphy to some extent, but that shown in Fig. 8 is perhaps more typical. In this the glass vessel is replaced by a stoneware jar, and the zinc is circular, of the shape shown by the dotted lines. The effect of this enlarged zinc is to expose more active surface and to reduce the internal resistance.

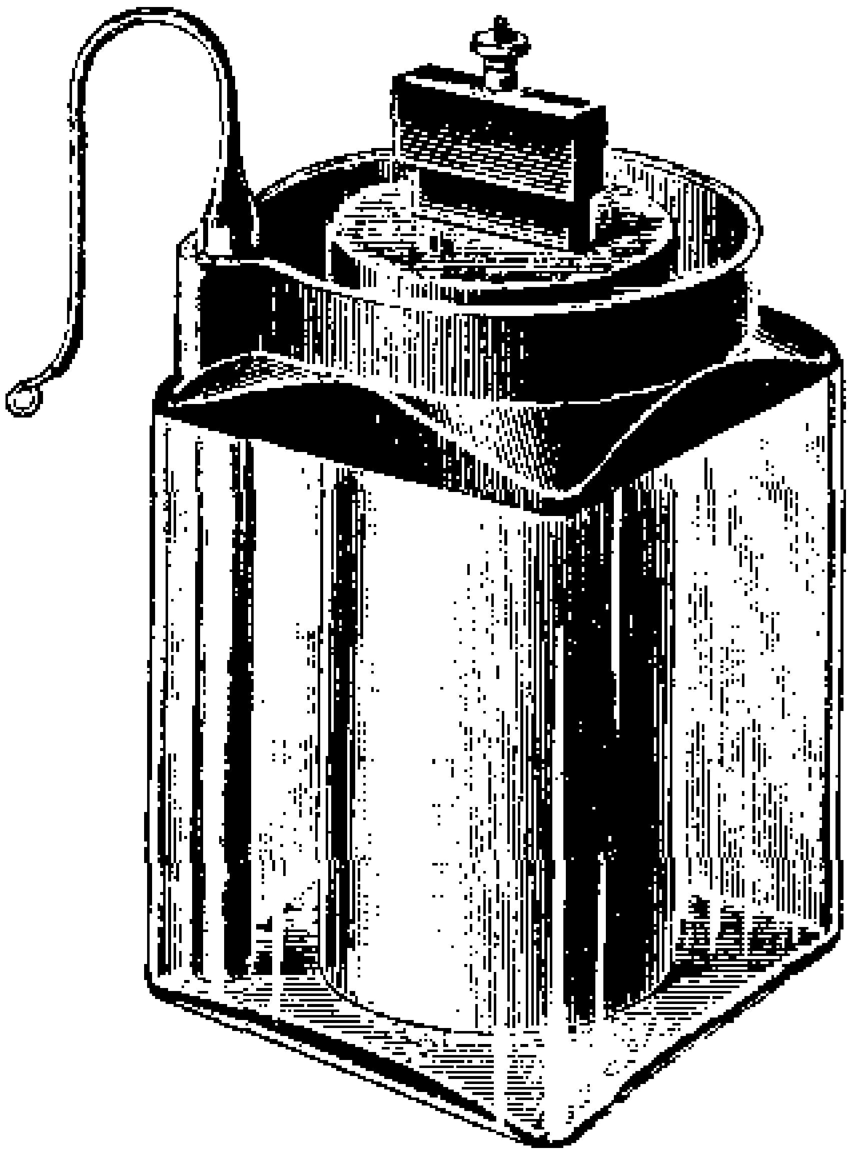


Fig. 7.—Leclanché cell.

Another form of Leclanché is illustrated in Fig. 9. This is the "agglomerate" cell, in which the porous pot is dispensed with. The broken manganese and carbon of the preceding cells are pressed together with a binding agent, so as to form a solid mass. Six pencils of this substance

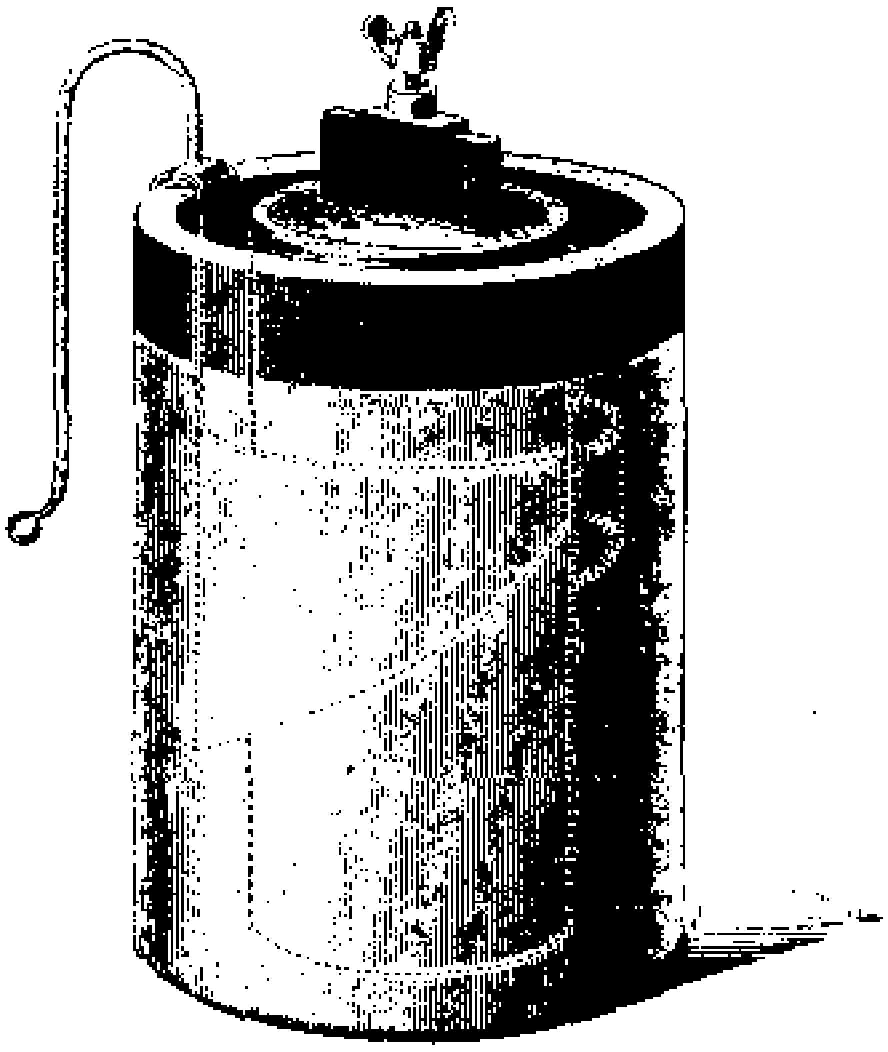


Fig. 8.—Leclanché cell, with circular zinc.

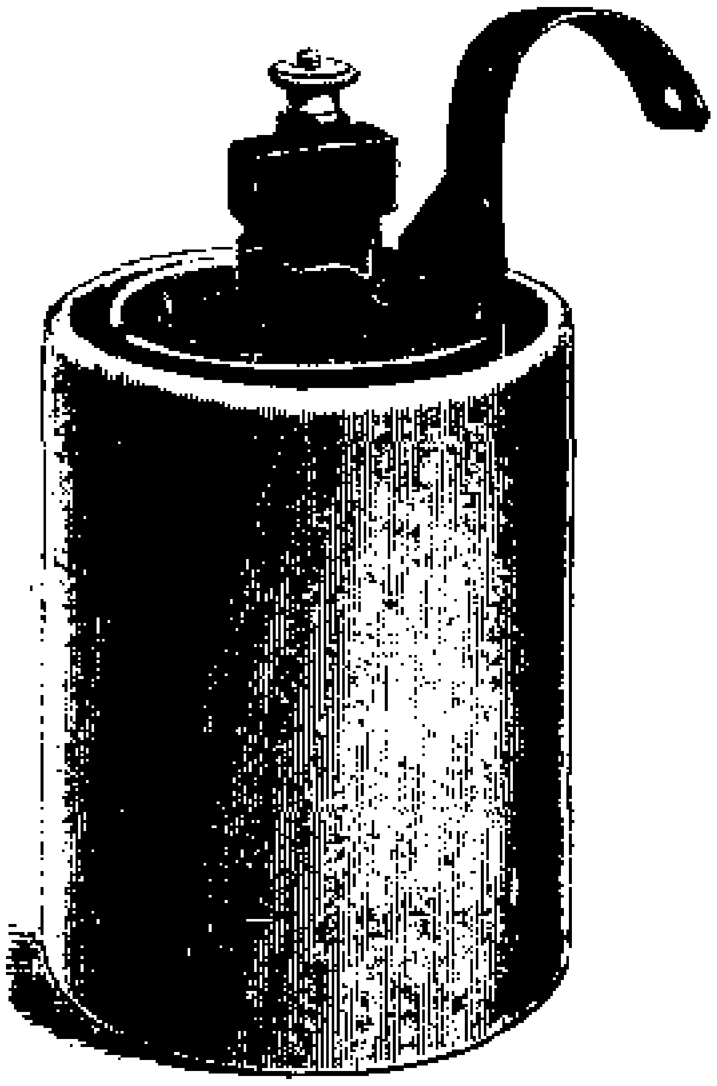


Fig. 9.—Six-block agglomerate Leclanché.

surround a carbon block suitably grooved to receive them. Around the whole a wrapping of canvas is placed, and a couple of india-rubber rings keep the whole in position. The zinc is of the same shape as that shown in Fig. 8. The internal resistance is thus brought very low, a small fraction of an ohm.

Dry Cell.—In this, generally speaking, the solution of the Leclanché cell is replaced by a moist paste containing similar materials. The advantage of the dry cell is its great portability. Having no liquid to spill, it may be placed in any position. The internal resistance is very low, and currents of considerable strength can be taken from it.

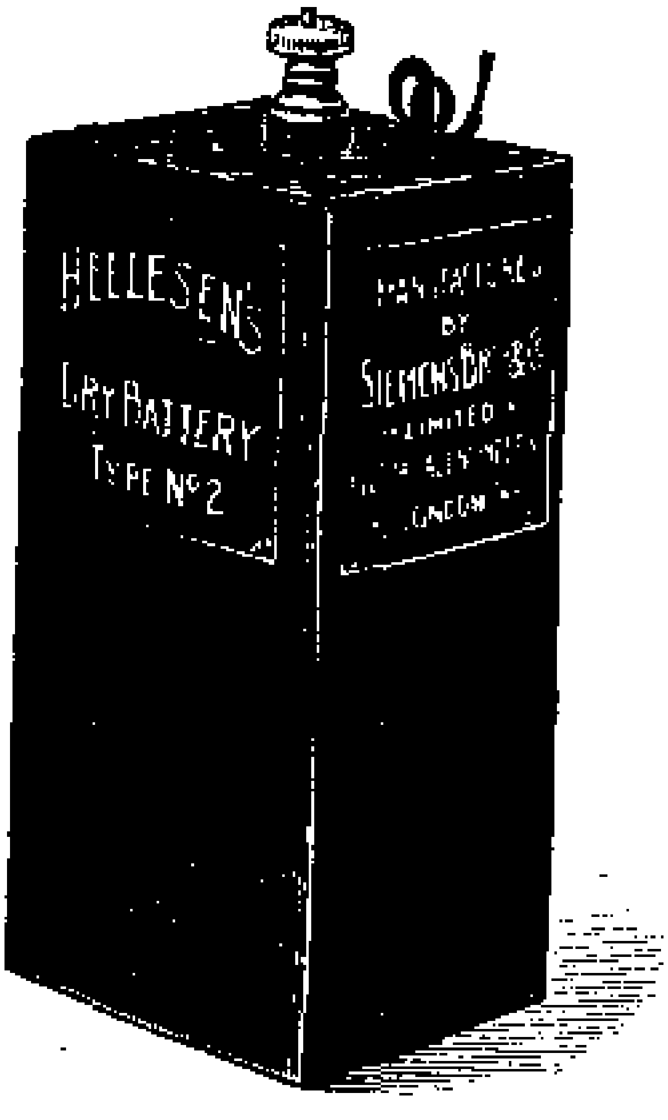


Fig. 10.—Hellesen's dry cell.

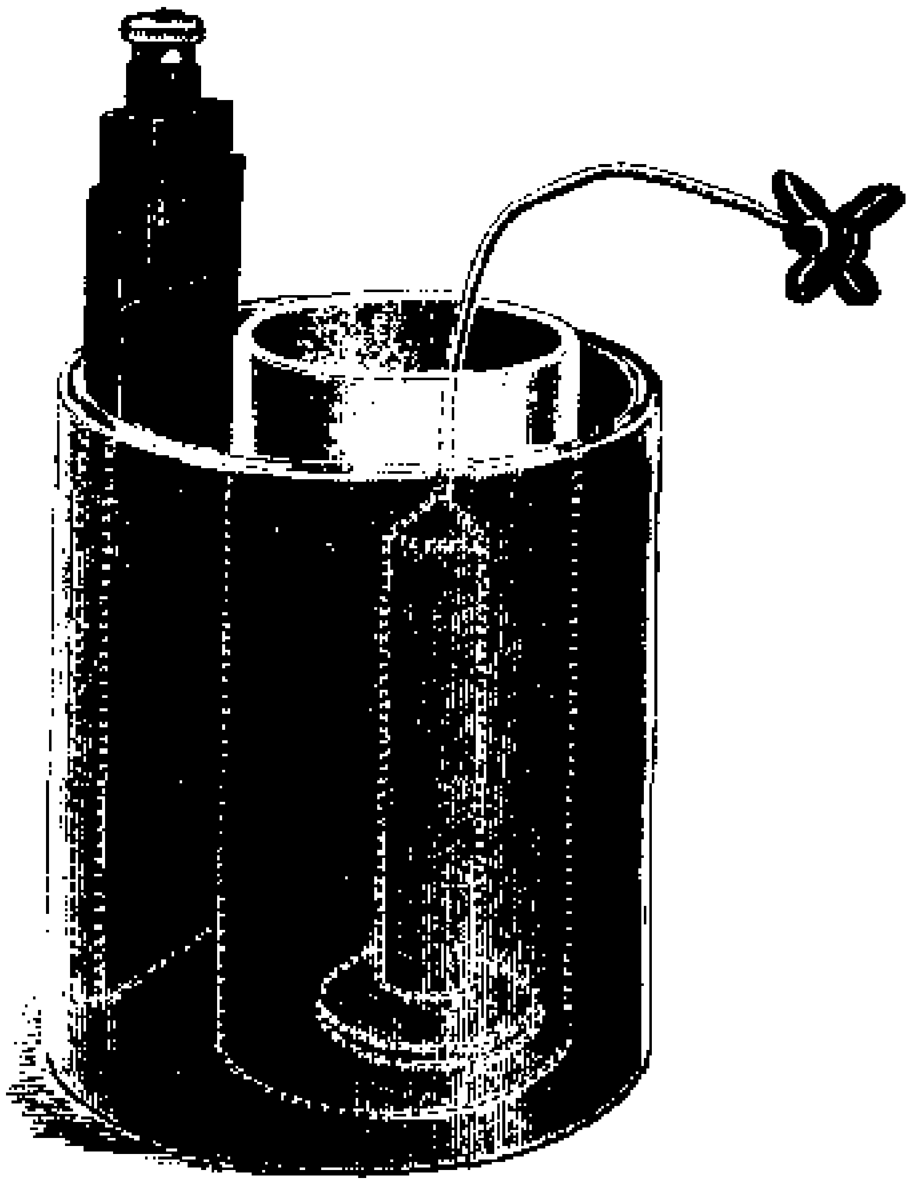


Fig. 11.—Bichromate cell.

Fuller's Bichromate Cell.—*This* form of battery is used where more powerful currents are required than can be furnished by the ordinary Daniell or Leclanché. In a porous cell is placed a stout rod of zinc having an enlarged base, and in the outer vessel a carbon plate. The zinc can easily be seen by the dotted lines in Fig. 11. The exciting fluid is dilute sulphuric acid, and the depolarizer a mixture of sulphuric acid and potassium bichromate = $K_2Cr_2O_7$ (hence the name of the cell). These two materials react to form chromic acid = H_2CrO_4. The latter itself could be used direct and with some advantage, but the indirect method of obtaining it is very much cheaper, and, although an additional by-product (potassium sulphate = K_2SO_4)

is produced, it is practically of no effect. A couple of ounces of mercury are added to the contents of the porous cell, and by this means the zinc is kept well amalgamated.

The action of the battery is as follows:—The sulphuric acid in the porous cell attacks the zinc and forms sulphate of zinc, which dissolves in the dilute acid. The hydrogen evolved engages with the chromic acid in the outer jar, robbing it of some of its oxygen, and thus forming water. Further action results in the formation of chromium sulphate and more water. The action is very involved, and perhaps the following equations, giving the first and final stages, may be of assistance:—

Preliminary action—

$$K_2Cr_2O_7 + 7H_2SO_4 + H_2O = 6H_2SO_4 + 2H_2CrO_4 + K_2SO_4.$$

Then—

$$3Zn + 6H_2SO_4 + 2H_2CrO_4 + K_2SO_4 = 3ZnSO_4 + Cr_2(SO_4)_3 + 8H_2O + K_2SO_4.$$

If we had used chromic and sulphuric acids in the outer jar, we should have had the following:—

$$3Zn + 6H_2SO_4 + 2H_2CrO_4 = 3ZnSO_4 + Cr_2(SO_4)_3 + 8H_2O.$$

That is, we should have avoided the formation of the potassium sulphate. This, however, does no harm unless the solution is allowed to get concentrated by reason of neglect. The sulphates of chromium and potassium then crystallise out as a double salt, known as chrome-alum, and the crystals adhere so tenaciously to the carbon plate that it is difficult to remove them.

The E.M.F. of the cell is 2·14 volts—twice that of the Daniell—and its internal resistance (quart size) 2 or 3 ohms. In working, the solution in the outer jar should keep a deep orange colour. When this begins to change to a dirty blue, attention should be given, and a fresh charge substituted for the old. Sufficient mercury should be retained in the porous cell to keep the zinc always clean and bright.

Secondary Cells.—One of the essentials of a primary cell is that the two electrodes shall be of dissimilar materials, one being easily acted on by the excitant and the other as inert as possible with regard to it. As soon, therefore, as the constituents of such a cell are put together it is ready to give out current. In a secondary cell, on the other hand, the original electrodes are alike, and equally unaffected by the solution in which they are placed. The mere setting up of such a cell, then, is not sufficient, but electrical energy, in the shape of a "charging" current, is necessary. Chemical changes are set up by this, so that at the end of the charge the two electrodes are no longer alike, but dissimilar, and have acquired the ability to give out electrical energy.

The primary battery, having given out all that it is capable of giving, must be again built up with fresh materials. The secondary battery simply requires a repetition of the first charge, and it is ready for a second giving out of energy. It is here that the superiority of the secondary over the primary cell is seen. Once erected, the former has never to be taken to pieces, but all the changes simply consist in applying charges to, and taking them from, the battery. The corresponding operations with a primary cell are mechanical, laborious and dirty, and involve general dismantling.

The electrodes of the original secondary cell were of lead, standing in dilute sulphuric acid. The passage of the charging current resulted in the formation on the surface of one of them of a layer of lead peroxide (PbO_2). The aim in making present-day accumulator plates or electrodes is to produce as much peroxide as possible on the positive plate, and to bring the mass of the plain lead negative to as porous or spongy a condition as possible. Originally these states were brought about by repeated chargings and dischargings of the plain lead plates, but this method is very expensive. Some plates, generally positives, are still treated in this way, but in place of a plain lead mass whose surface area was that of its two sides, the plates are now made to give enormously greater surfaces with the same or a smaller amount of metal. This is effected by making them with corrugated or otherwise broken surfaces, or by being built up of thin strips laid one upon the other with a space between, through which the electrolyte can pass, so that for a given quantity of lead the utmost area of surface shall be exposed. Such plates, "formed" by electrical means alone, are termed "Planté" plates, after the inventor who originally applied this method. The majority of plates, however, obtain this large surface area and porosity of substance by more mechanical means. The plate or metallic portion then becomes a "grid" or framework, the interstices and spaces of which are filled with a paste made up of the oxides of lead and sulphuric acid. Such plates are "pasted" or "Faure" plates (after the originator of the process). When this paste dries it is naturally of more porous texture than the solid metal, and the charging current can thus "get at" the inner regions of the mass as well as the surface. The positive plates are generally treated with a paste of red lead (Pb_2O_3) and the negative with a lower oxide (PbO) or *litharge*.

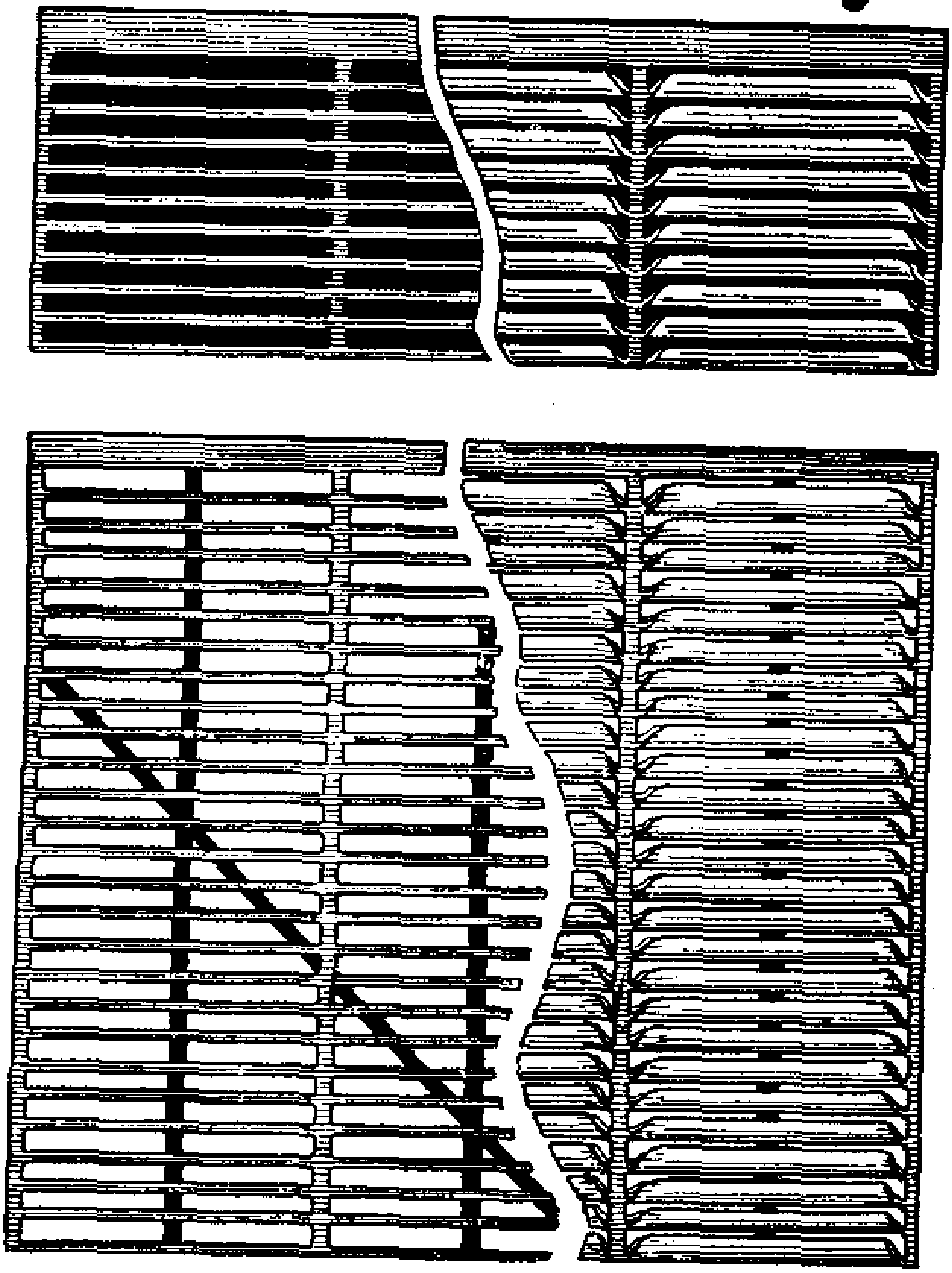


Fig. 12.—Hart plates.

Fig. 12 *illustrates the positive* (upper) *and* negative plates, made by the Hart Accumulator Co. On the left are the unpasted portions, whilst on the right is shown the alteration made after the pasting has been performed. Taking the negative, it will be seen that the plate consists of a number of horizontal strips, strengthened at intervals by a vertical rib. Further, shown in black are other inner ribs—that is, not extending to the surface, but limited to the central region of the plate. In the positive these central portions are continuous, forming a kind of web. Briefly, in the negative one can see through the spaces between the horizontal strips, but, with the positive, the centre of the plate is solid, but both sides alike are grooved. The groovings in the positive and the continuous spaces in the negative are all filled with paste, forced in under pressure. The plates are then subjected to a rolling process which causes the edges of the strips to curl upwards, as seen on the right. When the paste dries and contracts slightly—even it should become loose in the spaces between the strips—it cannot fall out, by reason of the curving of the edges.

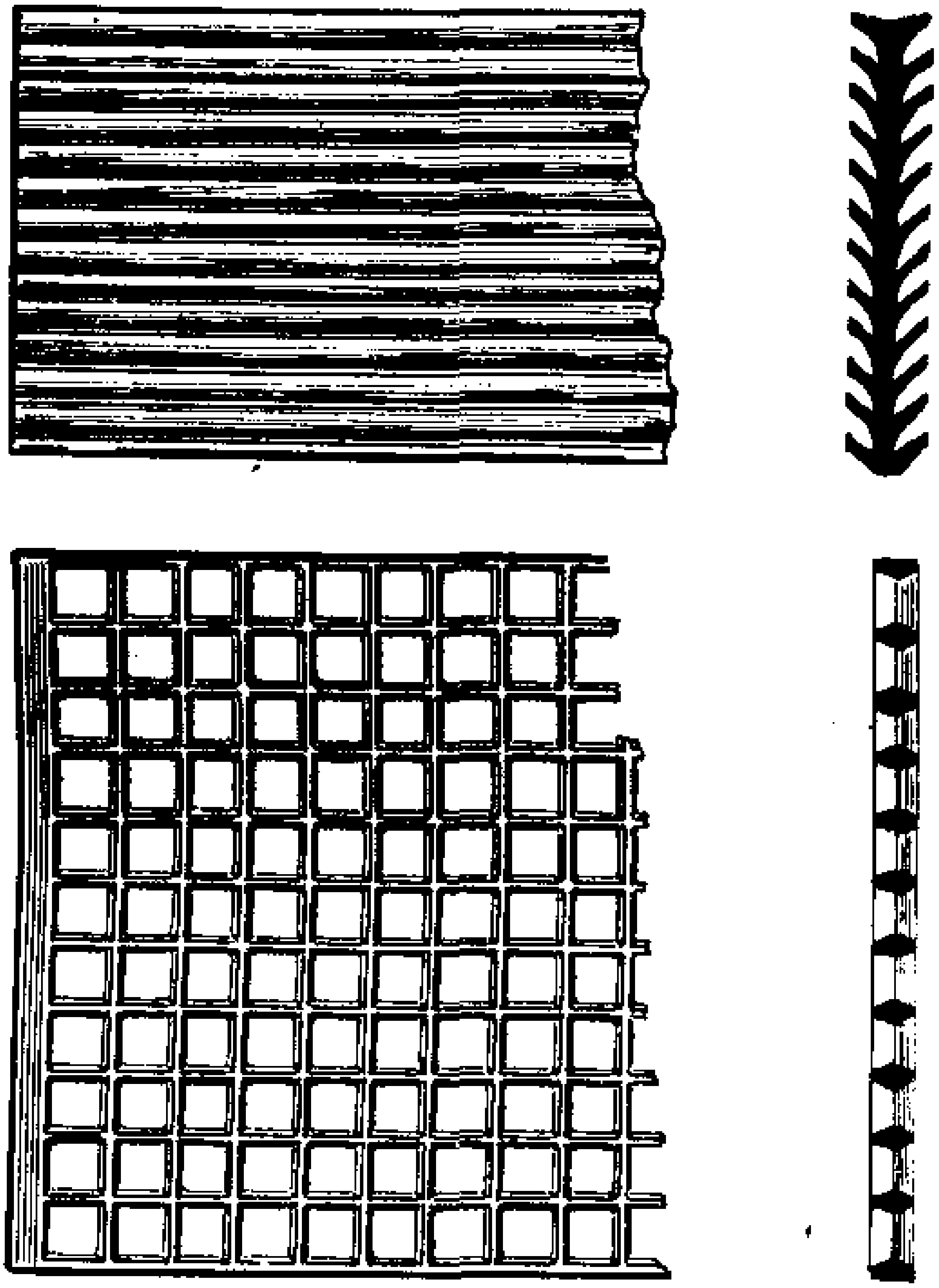


Fig. 13.—E.P.S. plates.

Fig. 13 illustrates in a similar manner the plates made by the Electrical Power Storage Co. The positive is a stout casting with upturned shelves on both sides. The negative is a simple grid, and it will be seen that the perforations in the grid are so made that the central portion is smaller than that at the sides of the plate. The result is that when the paste is forced in and dried each pellet is tightly imprisoned in its perforation by this central reduction.

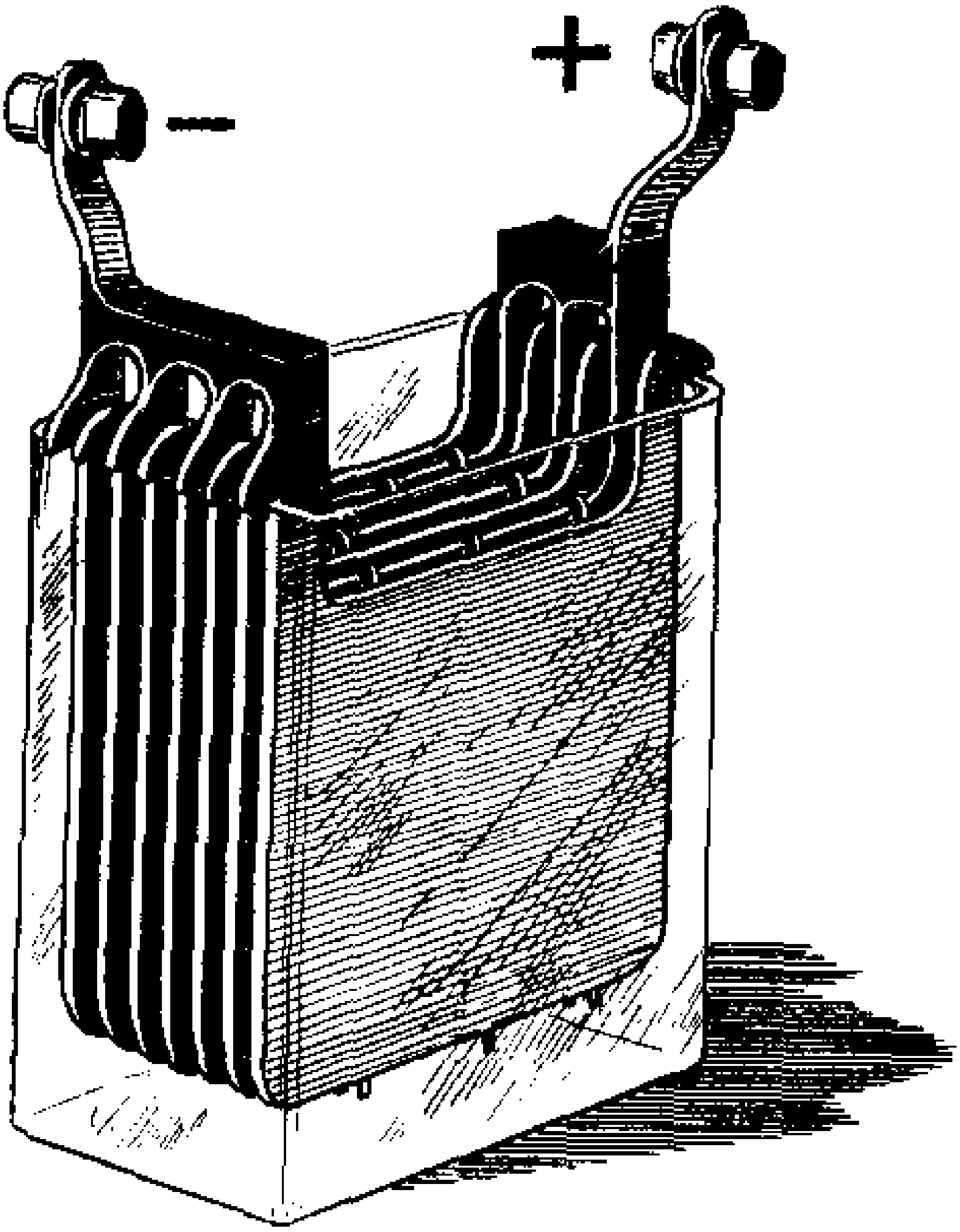


Fig. 14.—7-plate cell.

A small 7-plate cell is shown in Fig. 14. The three positive plates are "lead-burned" to a common lead bar which terminates in a lug, and forms the positive "section." Similarly with the four negative plates. The three positives are each bestridden by three ebonite separators—inverted **U**s with long legs—whose office is to keep the plates apart and prevent each from touching its neighbour.

We now consider the cell to be thoroughly charged. The texture, are masses of lead peroxide. The negatives, on the other hand, are highly porous or spongy masses of plain lead. The specific gravity of the dilute acid or electrolyte is at its maximum height, about 1,208 on the hydrometer, and the difference of potential between the two sections or the E.M.F. of the cell is slightly over 2 volts.

The cell is now brought into use, or commences to discharge. In a very short time the E.M.F. falls to 2 volts, and remains steady until nearing the end of the proper amount of discharge. The action going on in the cell is the coating of both plates with lead sulphate at the expense of the electrolyte, the specific gravity of which falls. The limit to which it is safe to discharge the cell can be gauged by the voltmeter and hydrometer. When the E.M.F. begins to sink below 1·9 volts and the specific gravity below 1,170, further discharge should not be taken, and recharging should commence as soon as possible, as, if the cell is left in a discharged state for any considerable period, it begins to deteriorate. The charging current then removes the sulphate from the plates, restoring sulphuric acid to the electrolyte, whose specific gravity again rises; and at the end of the charge the positives are again covered with lead peroxide and the negatives reduced to plain lead.

For office equipment with secondary batteries, see the author's *Telegraph Secondary Cell Installations*.

CHAPTER II.

UNIVERSAL BATTERY WORKING

WITH many circuits, each having its own battery, the number of cells in an office becomes very large. Further, some of these circuits may have very little business passing, so that their batteries are idle for long periods. Obviously, if we could utilise the same battery for several instruments, we should effect considerable economy. But to use the same battery on various circuits *in turn* would be impracticable, for they might all want it together; hence the battery must be permanently connected to all of them, and must be capable of supplying them all when working simultaneously. Besides the economy in the number of cells required by this plan, the cells actually in use will be worked more efficiently. In the case of Daniell cells, for instance, it is more economical to have them furnishing a permanent current than that they should have periods of idleness, for in these latter periods there is great waste going on. If, therefore, we utilise in useful work all that the cell is capable of giving, we are working it more efficiently.

With a battery of negligible resistance, it makes no difference whether one or ten circuits of equal resistance are working from it. Each will get the same current when all the others are *working as when itself alone is working.* In the latter case it gets a current of a certain value. When the other nine are working with it, the resistance is reduced to one-tenth and the current increased to ten times its former strength, which, divided among the ten, gives each the same value.

With primary cells, however, the battery has necessarily a considerable resistance. Therefore, when two equal circuits are *working together from the same battery* we halve, not the *total* resistance, but the external only. Hence each of the two circuits, working together, will not get so much current as when either is working alone. The greater the number of circuits thus grouped the greater the variation in current will become. Also, the greater the internal resistance of a battery the fewer lines it is possible to put upon it. The following rules are laid down in *practice*:—

The lines to be grouped must not differ in resistance by more than 25 per cent. Thus, if the highest resistance be 2,400 ohms, no line less than 1,800 ohms should be included. Circuits having a less resistance than this can be artificially raised by the addition of resistance coils. These should be placed in the battery leads of the respective lines, so as not to be in circuit for the received current. These added resistances should be of such a value as to bring the line to not less than 25 per cent. below the highest, but the nearer they approach the highest the better.

The resistance of the battery must always be considerably less than the combined resistance of all the circuits grouped upon it. If the battery is settled, then the number of lines possible to connect to it will be limited by the preceding. If, however, it is desirable to group a considerably greater number than this battery will take, it may be possible to use a different battery. The substitution of Bichromates for Daniells, for instance, gives double the E.M.F., and also a reduced resistance per cell. Further, it may be advantageous to form several groups, one of the circuits of very high resistance, another of very low, and so on.

A battery employed for universal working (single-current) will have one pole earthed at the battery-box and the other teed off to the instruments, the function of the keys being simply to connect the free pole to the lines. The same battery, obviously, cannot be used to send positive and negative currents; hence for double-current, single-needle, &c., and for a group including up and down single-current sets, it is necessary to employ two batteries (or a "double" battery). The positive pole of one and the negative of the other are earthed at the battery-box, and the free poles are teed off to the instruments to send negative and positive currents respectively. The number of cells for double-current, &c., circuits is thus twice the number required for the circuit of highest resistance when worked by an independent battery.

Use of Secondary Batteries.—For universal working these are obviously well fitted. One double battery then takes the whole of the circuits. The plan of bringing all the circuits to approximately the same resistance and of applying the full E.M.F. of the battery to all, as in the primary adopted. Instead, the secondary battery is tapped at various points, so as to give different voltages for circuits of different resistances. The standard voltages are 40, 80, and 120, positive and negative, for the main batteries, and 24, positive and negative, for the local batteries which work the sounders, &c., and short lines. Where the nearest available voltage is too high, resistances are employed in the battery leads, as previously indicated.

The arrangement of the cells is shown in Fig. 15. In addition to the number required for voltages named, extra sets are provided which are available for charging. By suitable arrangements each set of 20 main cells is shifted in position with regard to the rest, so that all the sets take an equal share in the work before the final shift in the cycle brings them to the charging position.

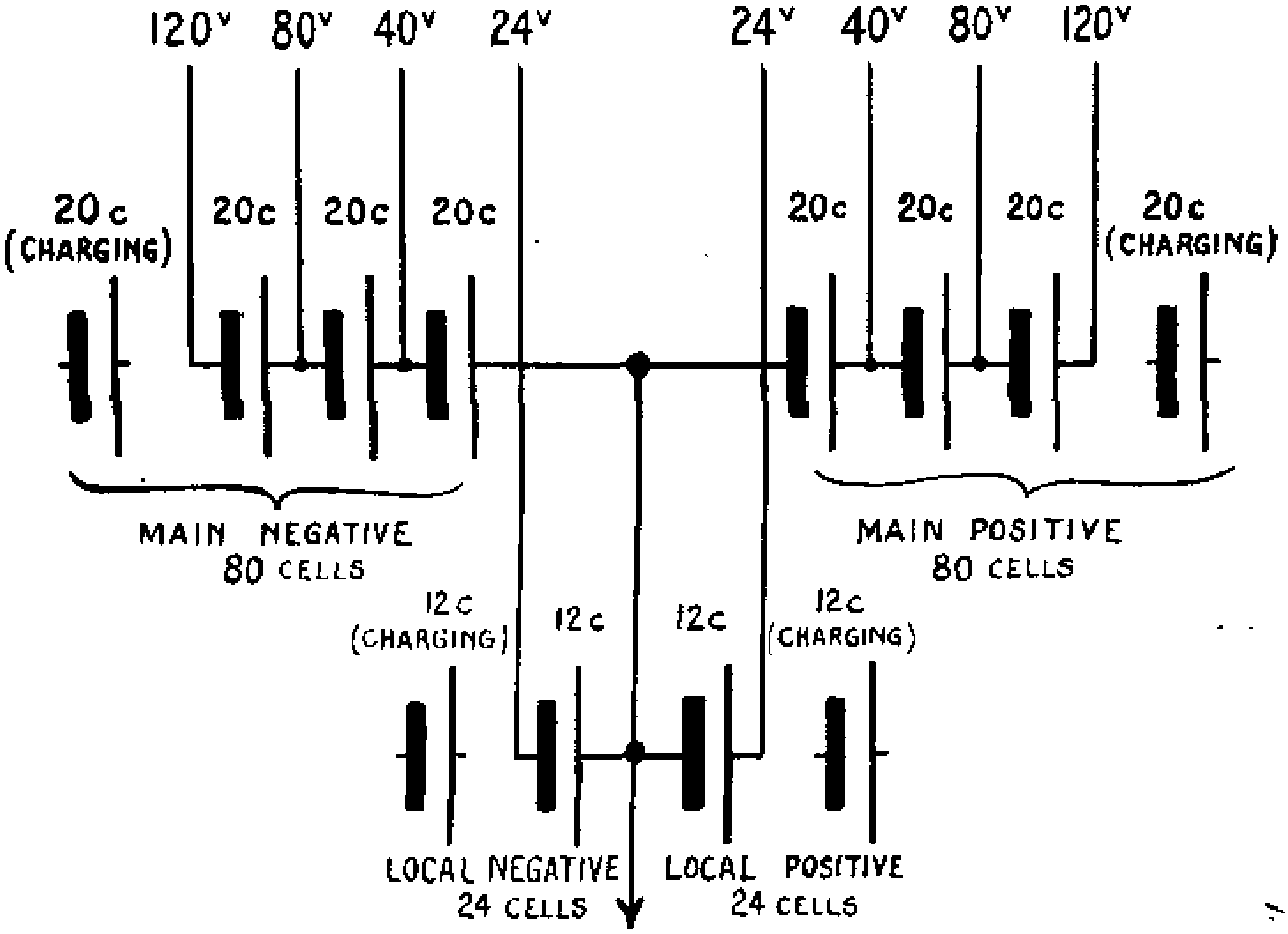


Fig. 15.—Arrangement of voltages.

We now have to consider in detail the alterations which have to be made in the connections of various sets of apparatus when universal working is set up.

Connections of Apparatus.

Single Needle.—Fig. 16 gives the ordinary connections with separate battery. By putting terminal A to earth and B to line we have an "up" station. With B to earth and A to line we have a "down" station. At an "intermediate" office the down line—*i.e.*, the line proceeding to the down station—is

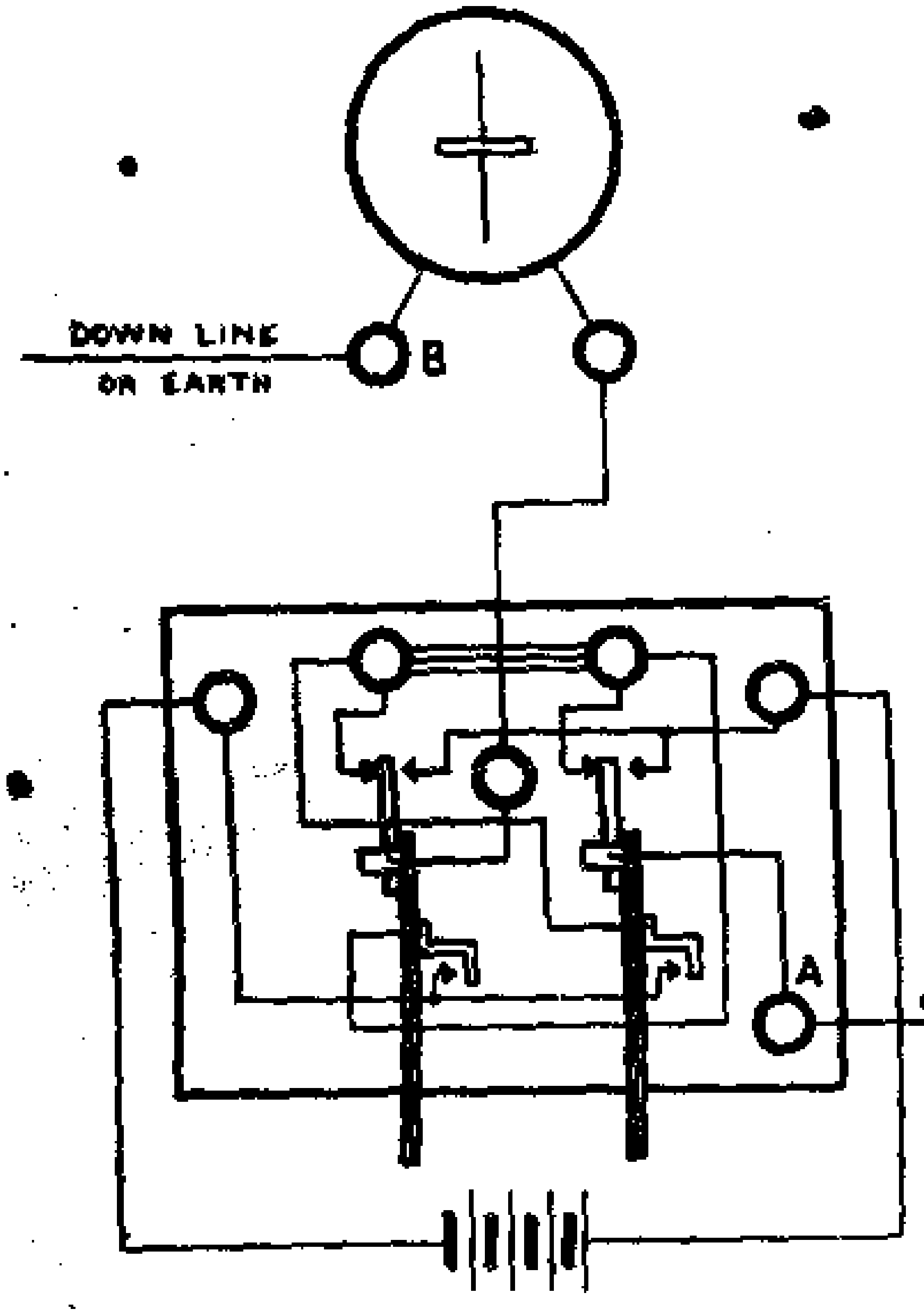


Fig. 16.—Single needle: ordinary, with primary batteries.

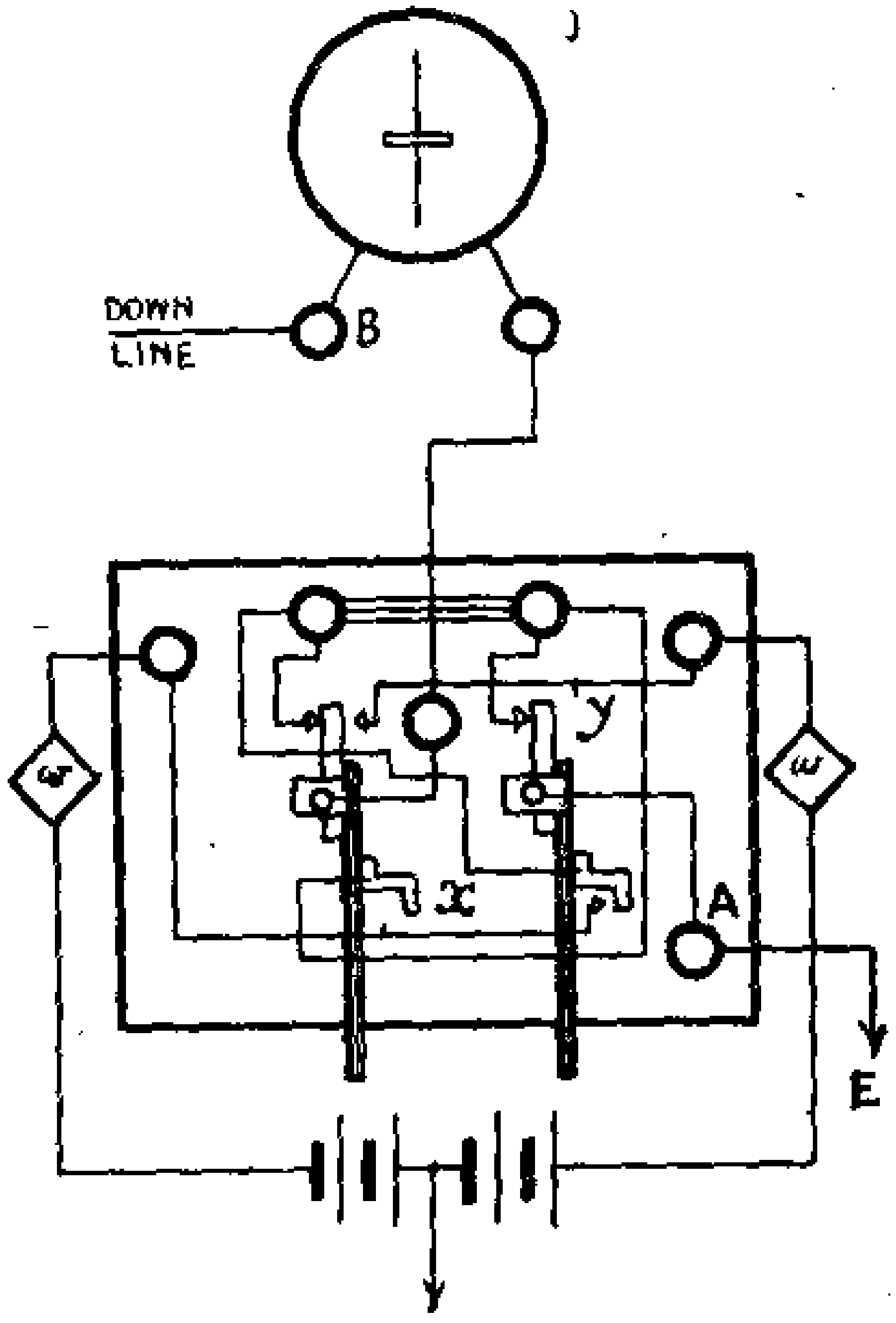


Fig. 17.—Single needle: universal batteries, up station.

connected to terminal B and the up line to A. Thus, with these exceptions, all stations are connected up alike. When the left-hand tapper is depressed the positive pole of the battery is put, through the upper back contact and axle of the tapper, to the dial and down line. At the same time the negative pole is brought to terminal A by means of the front contact of the depressed key, the lower back contact and axle of the other. When the right-hand tapper is put down the battery is reversed. Thus the depression of either key connects one pole of the battery to the line and the other to earth, and when both are at rest the battery is completely insulated.

Single needle: universal batteries, up station, Fig. 17. Instead of a single battery with insulated poles we now have the + and − poles of two separate batteries whose other ends are permanently to earth. It is necessary, therefore, to disconnect the front contact *x* of the left-hand key and the top-back contact *y* of the other, otherwise these will put the left- or right-hand battery to earth when the corresponding tapper is depressed. The putting down of the left key now simply connects the + pole to the coils and line by means of its top-back contact and axle. The depression of the right key puts the − pole to line by means of its front contact and the lower-back contact and axle of the other key. The blocks *w w* show where the equalising resistances, if required, must be placed. The only change required in the connections is thus—

Contacts *x* and *y* disconnected.

Single needle: universal batteries, down station, Fig. 18. As before, contacts *x* and *y* must be disconnected.

With ordinary separate battery the line would be brought to terminal A. But the dial must be included in the line: hence the line is taken to the coils. As this is a down station the depression of the right-hand key must send + to line: the batteries must, therefore, be reversed. This, and the fact that the depression of the distant (up) station's right-hand key sends − to line, necessitates the reversal of the coil terminals. To make clear these various alterations as compared with the ordinary diagram of Fig. 16, they are all indicated by asterisks. Summarising, we have—

Contacts *x* and *y*	disconnected.
Line and earth	reversed.
Batteries	,,
Coil terminals	,,

Single needle: universal batteries, intermediate station. The connections are precisely the same as in Fig. 16, and the contacts *x* and *y* must not be disconnected, as the depression of either key is required to put the positive battery to A and the negative to B, or *vice versâ*. As the two batteries are to earth the up and down lines are worked as two distinct circuits, and the dial being on the down line there is no indication of the signals passing to the up side.

Unless the resistances of the two sides are fairly equal, unequal currents will be sent to the up and down stations. For perfect symmetry the up line should be 200 ohms less than the down, since the latter includes the coils. Further, if the total resistance of the whole circuit be the same as that in the two preceding cases, resistance coils will be required in the battery leads, because *both* batteries being in use at once the E.M.F. applied to the circuit is doubled.

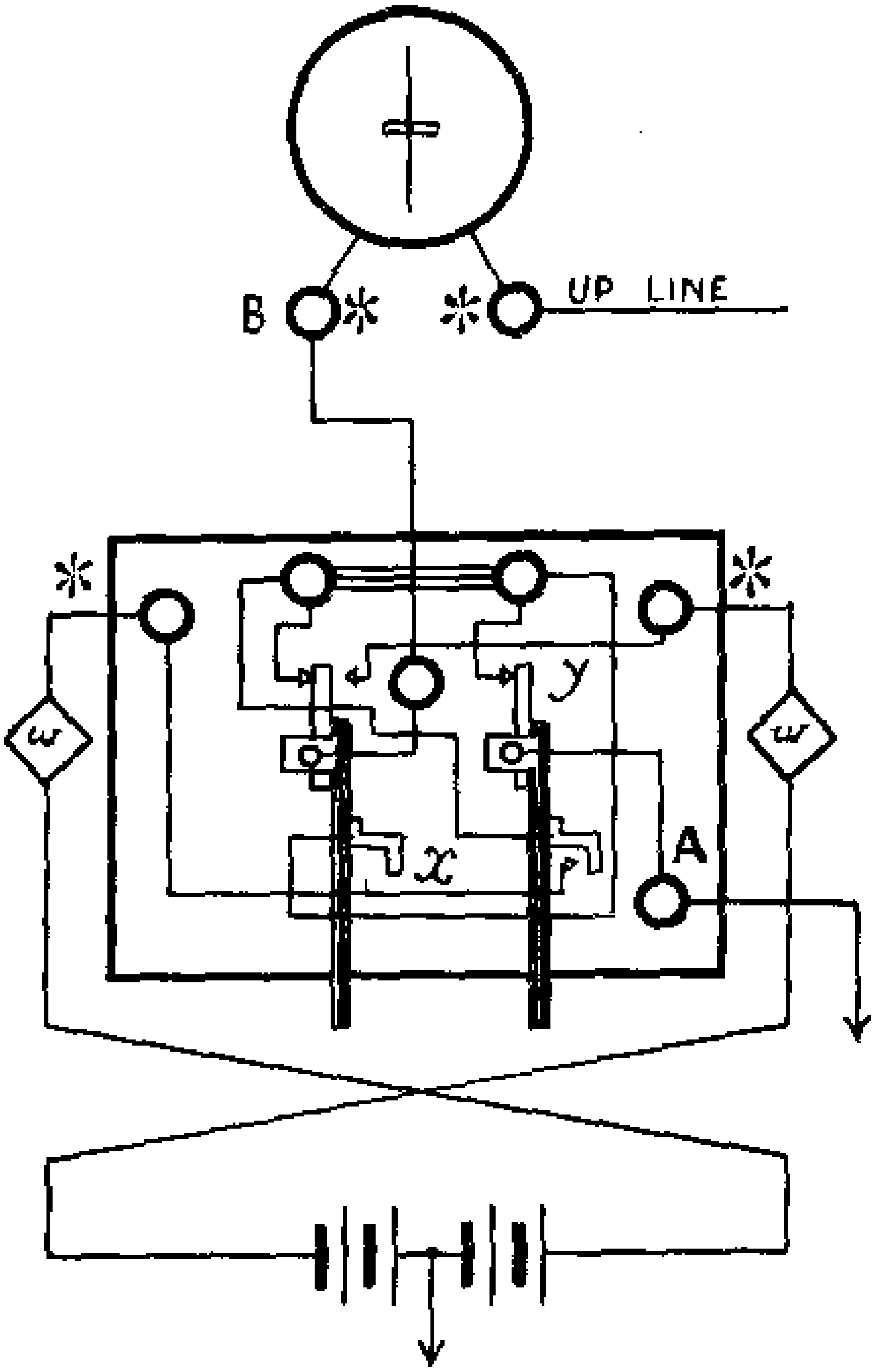


Fig. 18.—Single needle: universal batteries, down station.

For working single needles on the universal plan, primary batteries are usually employed, and the equalising resistance coils are those known as "coils, resistance, various," consisting shell. Where secondaries are installed, single needles are generally replaced by double sounders wound to 900 ohms.

Double Sounder.—Fig. 19 gives the ordinary connection with separate battery The remarks relative to Fig. 16 apply here. The relay is on the receiving circuit only, but the galvanometer, occupying the position of the dial of the single-needle instrument, shows both sent-out and received currents. The strap connecting the two back terminals of the commutator must be removed and its place occupied by the relay coils.

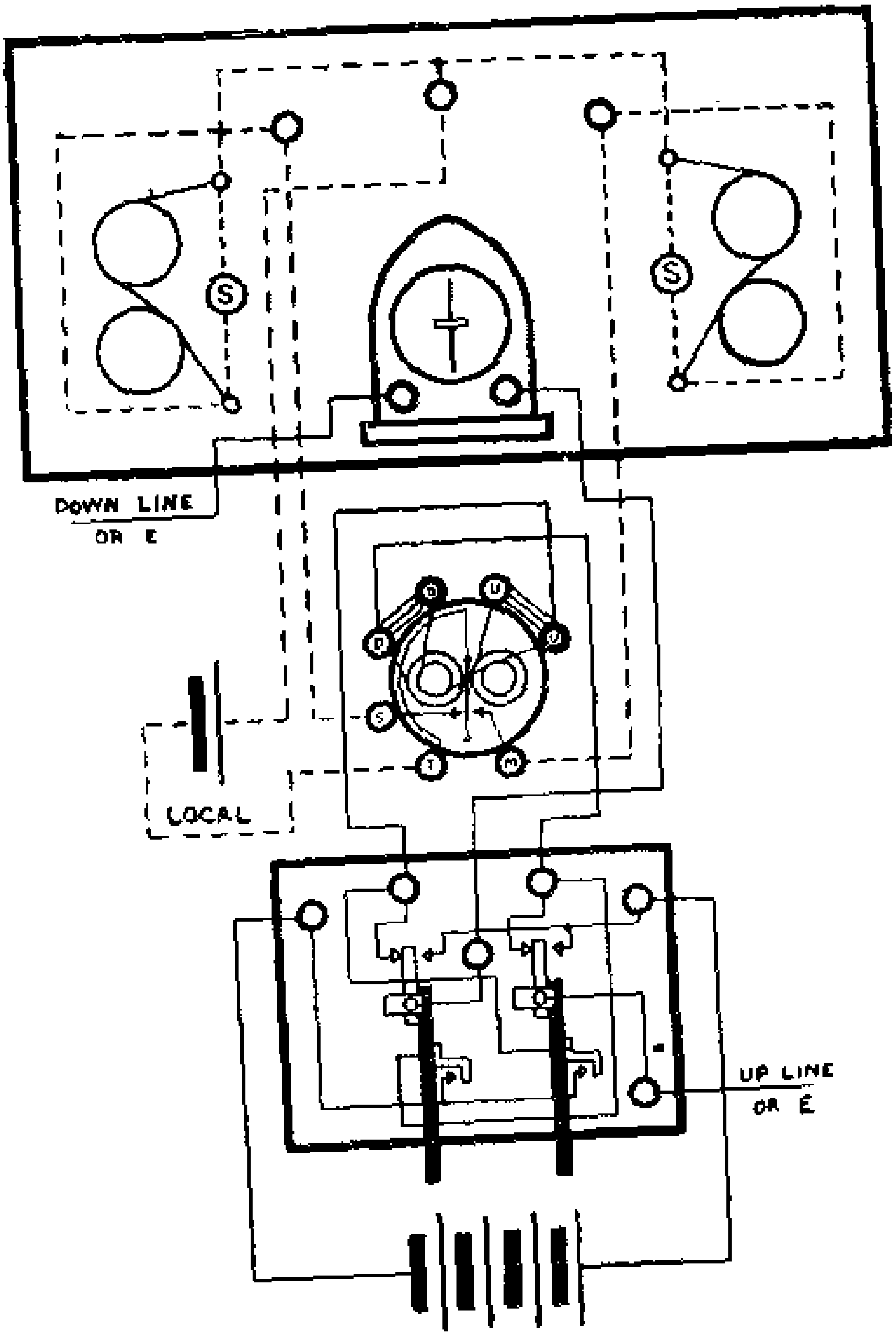


Fig. 19.—Double sounder.

Double sounder: universal batteries, up station, Fig. 20. See remarks on single needle, Fig. 17. Contacts x and y must be disconnected. It is assumed in the rest of the universal battery diagrams in this chapter that secondary cells are in use. The resistance coils shown in the battery leads of Fig. 20 are enclosed in metal cases, and are primarily intended, not as equalising, but as *protective* resistances, although they sometimes combine both purposes. Their values are 2 ohms per volt of the power used,

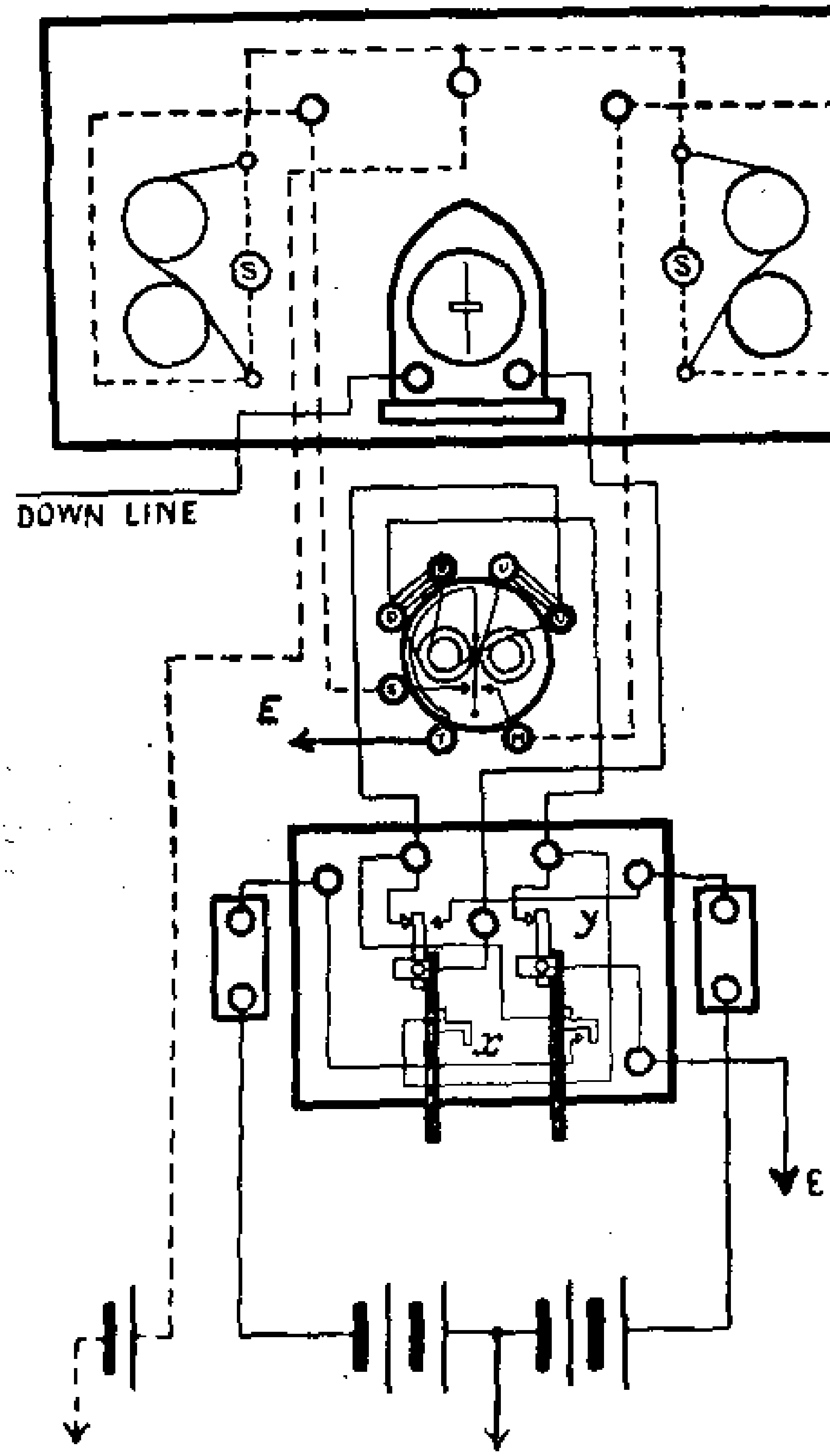


Fig. 20.—Double sounder: universal batteries, up station.

so that if all the resistances were cut out of the circuit except this coil the current shall not exceed half an ampere. The metal case is to afford easy radiation of the heat developed. These are used for the 24- and 40-volt leads, but for 80- and 120-volt leads glow lamps of 16 candle-power, 100 volts, are used.

The sounders are wound to 1,000 ohms and their shunts to 10,000, so that the effective resistance of each sounder is 900 ohms. Twenty-four volts are invariably used for the local circuits, and in these no protective resistance is placed. The local battery, as well

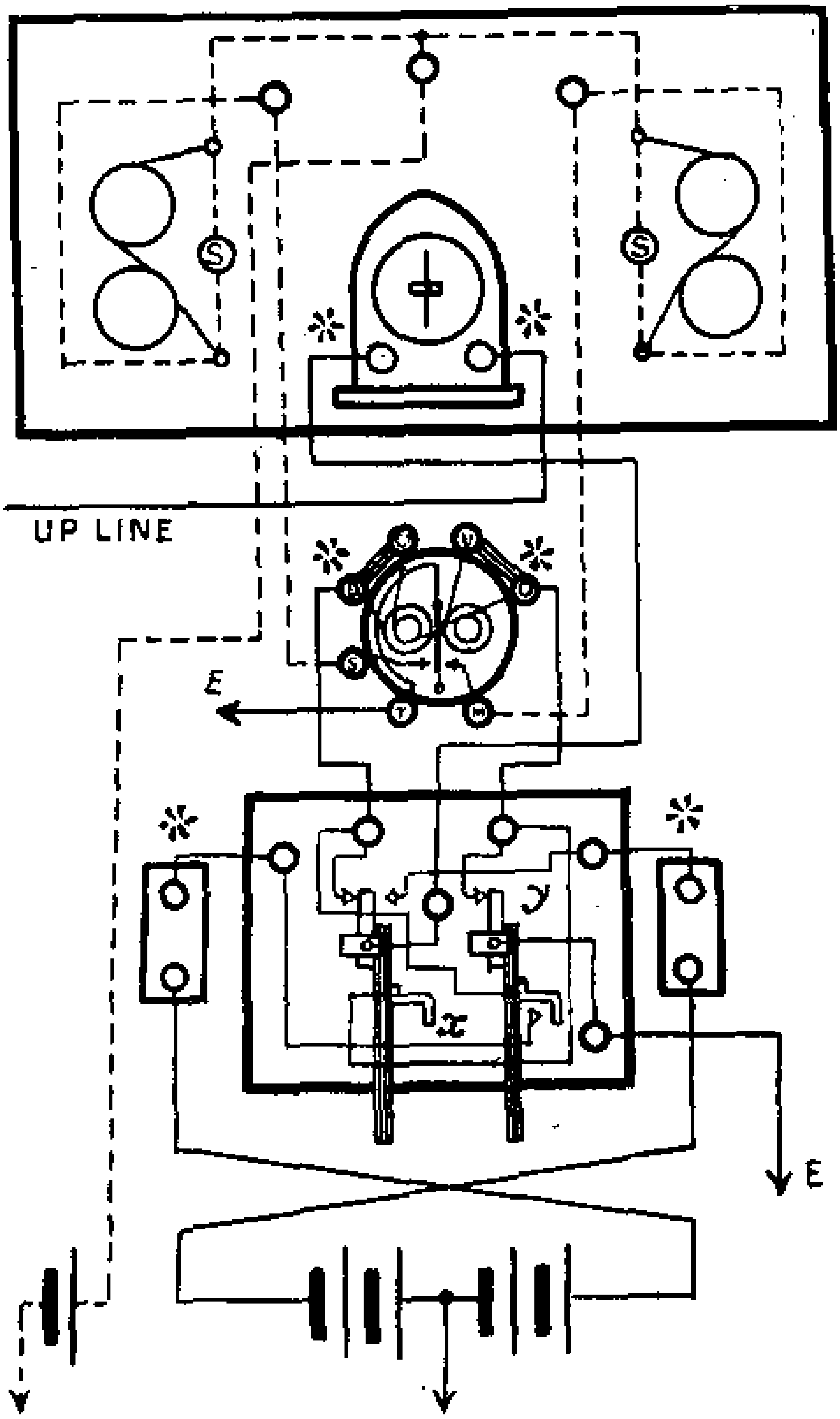


Fig. 21.—Double sounder: universal batteries, down station.

as the mains, is earthed; hence some point of the local circuit must also be earthed. Wherever a relay is employed this point is the terminal T to which the tongue, framework, and case are connected. This practice prevents any shock being received by an operator in the act of adjusting or touching the relay.

Changes in connections from ordinary diagrams are thus—

Contacts x and y disconnected.
Terminal T of relay earthed.

Double sounder: universal batteries, down station, Fig. 21. See preceding paragraph and remarks under single needle, Fig. 18. Alterations of connections, as compared with Fig. 19, are all indicated by asterisks. Summarising—

Contacts x and y	disconnected.
Terminal T of relay	earthed.
Line and earth	reversed.
Batteries	,,
Galvanometer terminals	,,
Relay coil terminals	,,

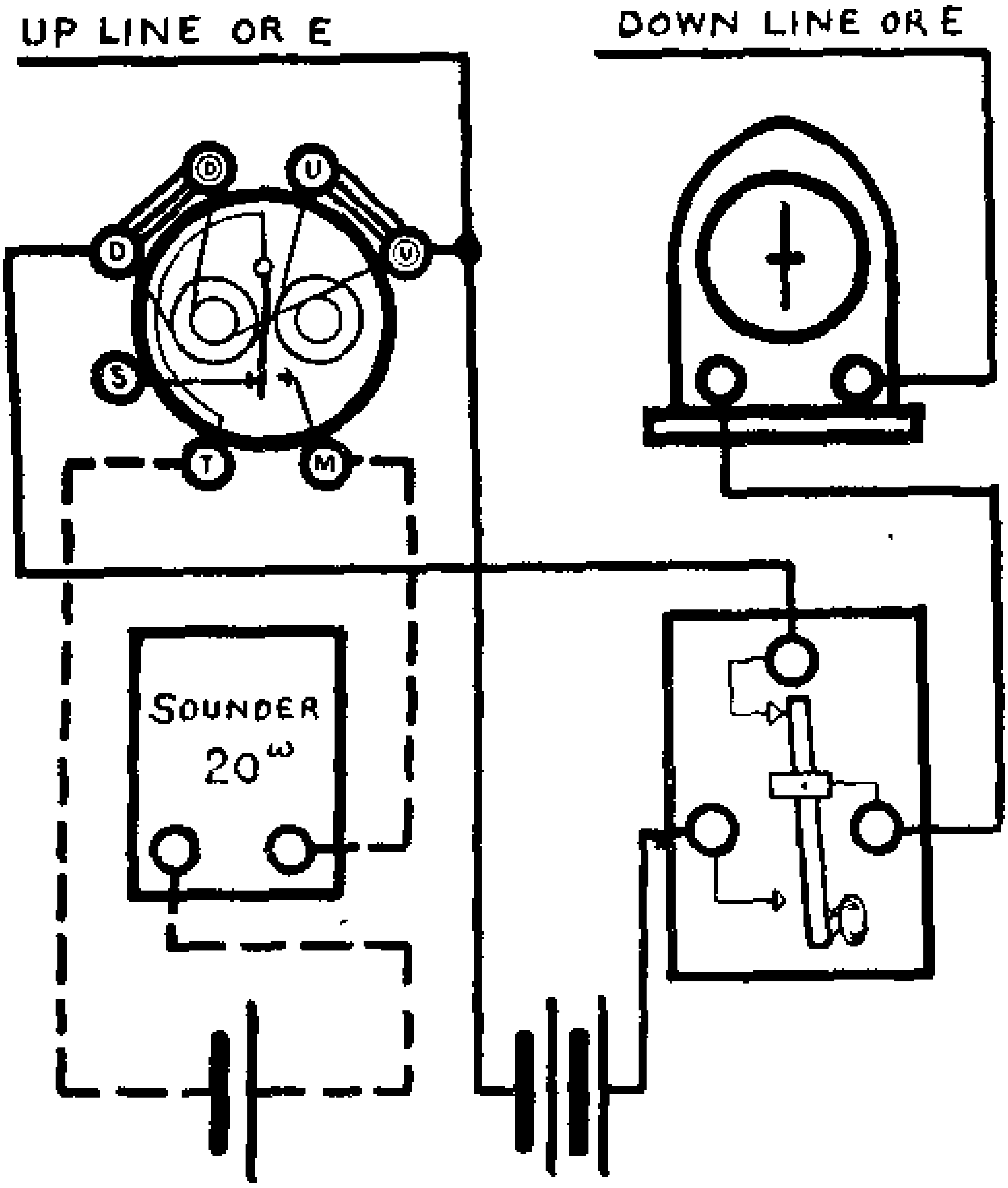


Fig. 22.—Single current, with relay.

Double sounder: universal batteries, intermediate station. See remarks under similar station single-needle. Connections precisely as in Fig. 19, and contacts x and y must not be disconnected. The galvanometer (30 ohms) occupies the place of the single-needle coils in the down line. There is thus no check upon the signals passing out to the up line.

Single Current, with Relay.—Fig. 22 gives the ordinary connections with separate battery.

Single current, with relay: universal batteries, up station, Fig. 23. Little comment is needed here. The sounder is wound to 900 ohms (1,000 coils and 10,000 shunt), and the T terminal of relay earthed. The coil x is metal-cased.

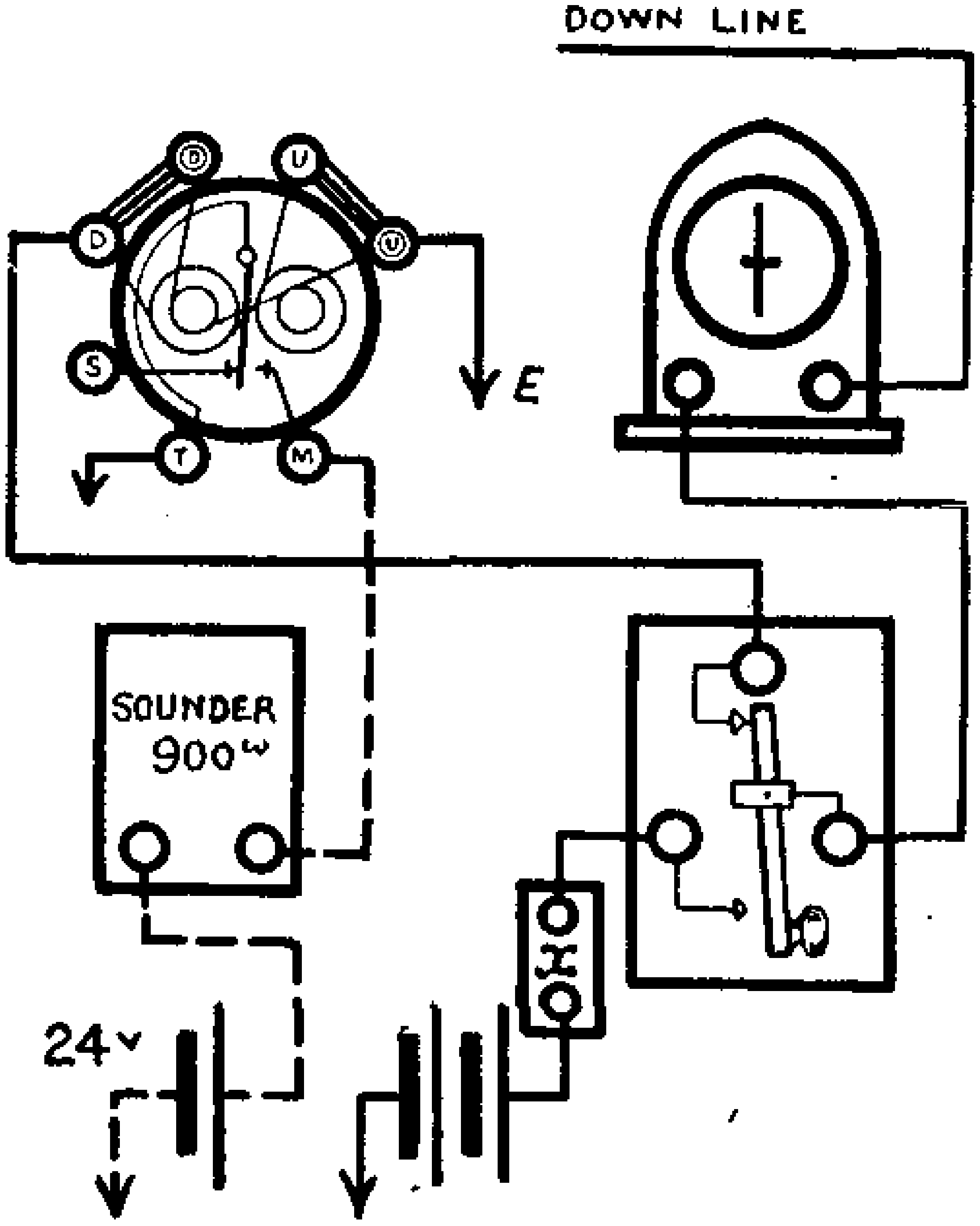


Fig. 23.—Single current, with relay: universal batteries, up station.

Single current, with relay: universal batteries, down station, Fig. 24. With a down station, the line would normally go from terminal (U) of relay, but as we require the galvanometer to be in circuit with the line, the latter must be brought to the galvanometer. As this is a down station, the depression of the key must send — to line; the batteries must, therefore, be reversed. This, and the fact that the depression of the distant (up) station's key sends + to line, necessitates the reversal of the relay coils,

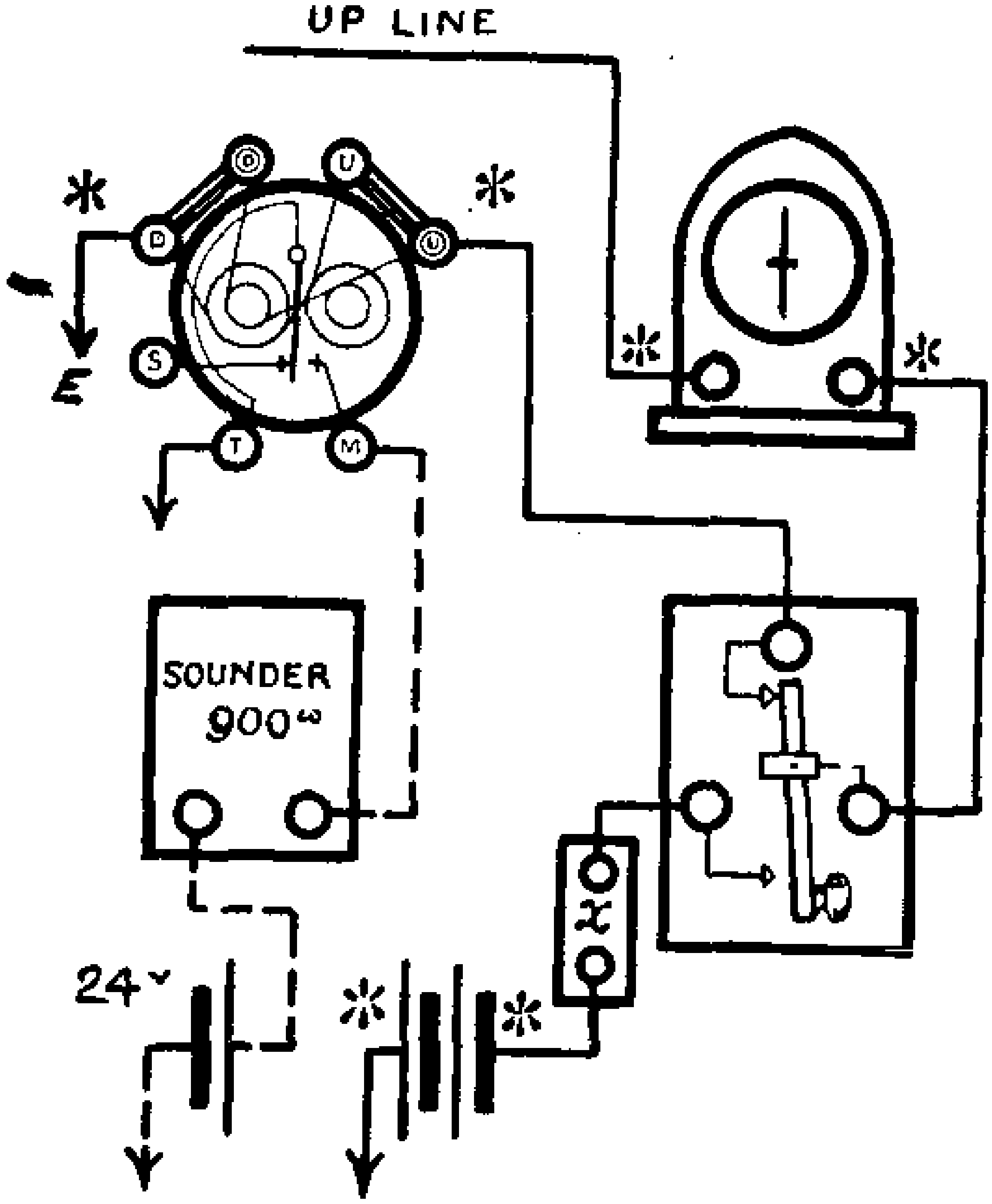


Fig. 24.—Single current, with relay: universal batteries, down station.

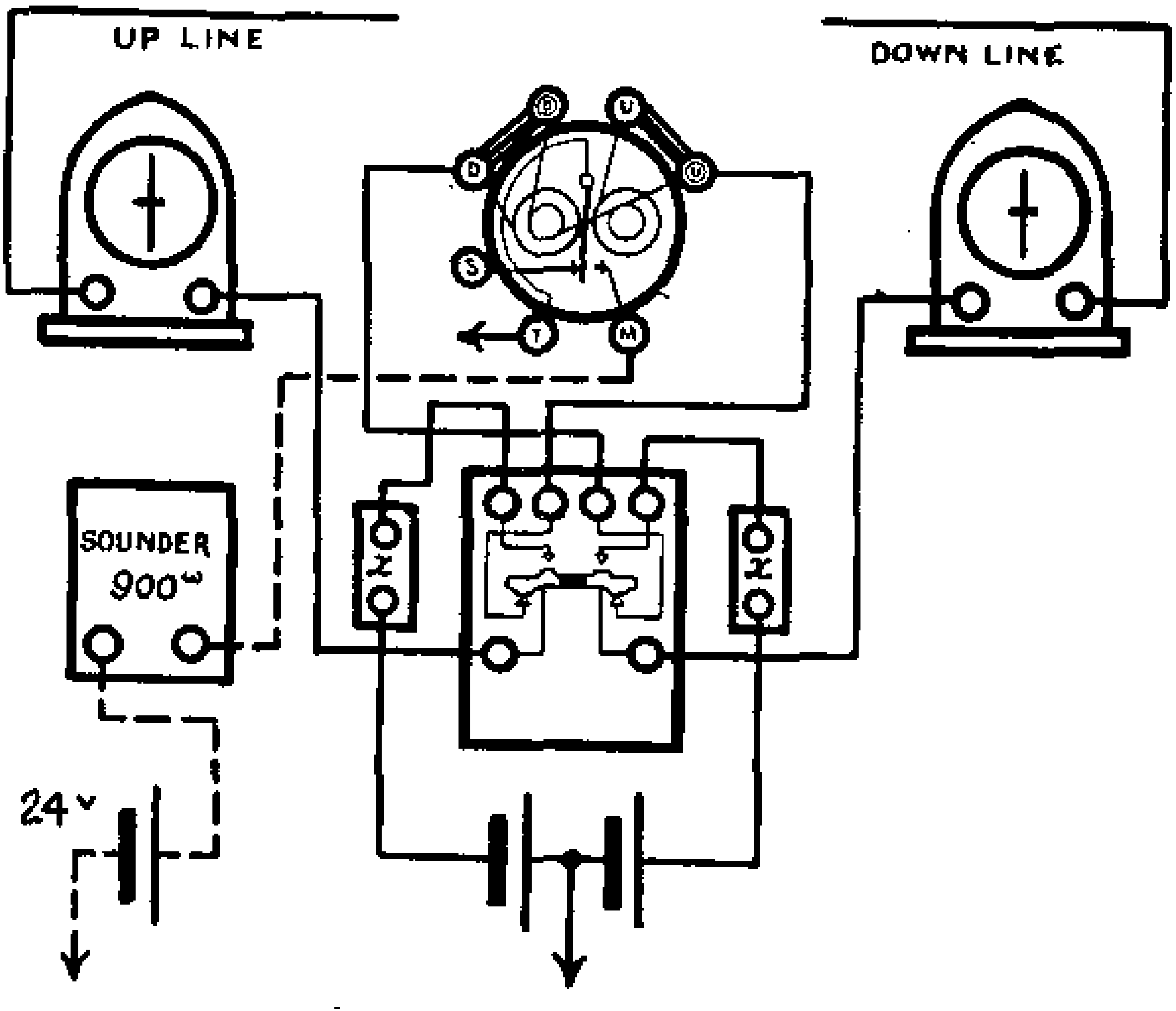


Fig. 25.—Single current, with relay: universal batteries, intermediate station.

and also of the galvanometer coils, in order that the deflection of the top of the needle of the latter may be to the right. As before, these reversals are indicated by asterisks, and summarised thus—

Line and earth	reversed,
Batteries	,,
Galvanometer terminals	,,
Relay coil ,,	,,

Single current, with relay: universal batteries, intermediate station, Fig. 25. It is clearly impracticable to work both lines by an ordinary single-current key; hence a double-current key with six terminals is employed. In order also that the current passing out to the up line may be observed, as well as that to the down line, another galvanometer is added to the equipment.

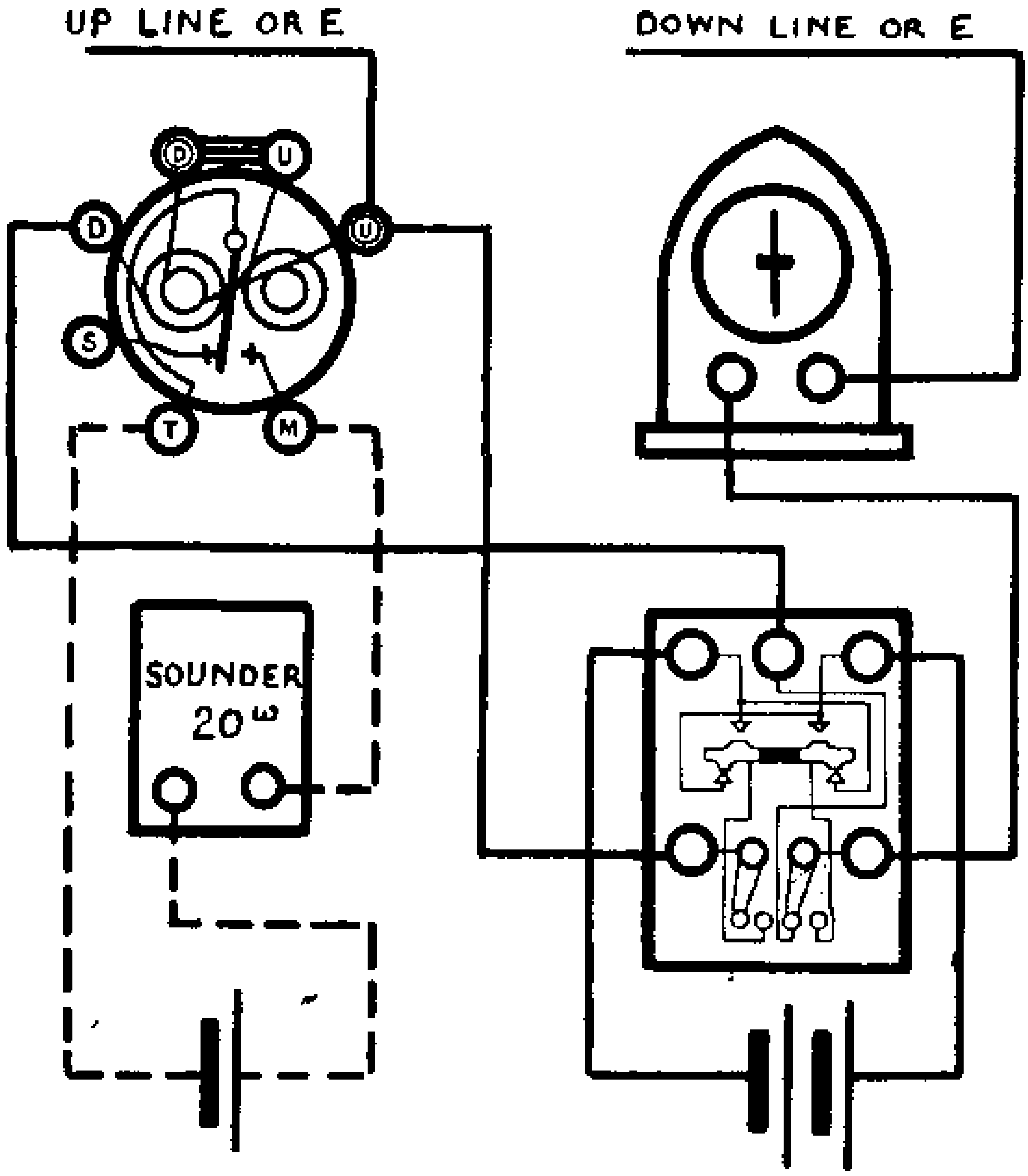


Fig. 26.—Double current.

As the right and left metal-cased resistance coils are permanently in the down and up sending circuits, advantage may be taken so to arrange their values as to equalise the resistance of the two sides. The coils will thus be unequal, one acting partly as a protective and partly as a balancing resistance.

Double Current.—Fig. 26 gives the ordinary connections with separate battery.

Double current: universal batteries, up station, Fig. 27. For sending, as we have two separate earthed batteries, we need only a kind of single-current key and the means of cutting-off the batteries. The double-current key may, indeed, be considered as a pair of single-needle tappers rigidly fixed together, and the substitution of the special key shown in Fig. 27, with a single plain lever, four terminals, and switch, is the equivalent of the removal of the contacts *x* and *y* from the tappers in Fig. 17. The changes from the ordinary diagram (Fig 26) are thus:—

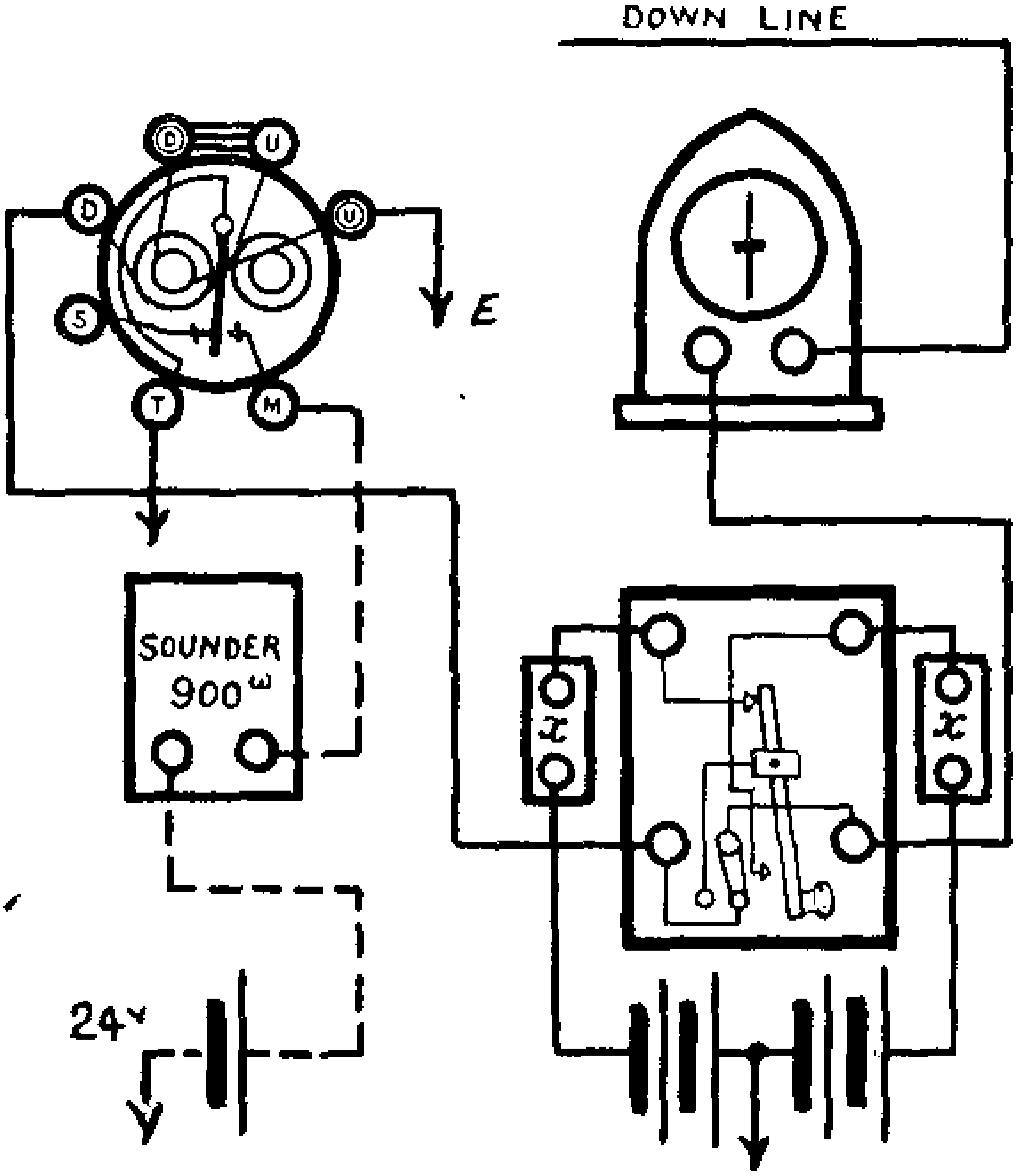


Fig. 27.—Double current: universal batteries, up station.

Substitution of "S.C. key with switch" for ordinary D.C. key.

Double current: universal batteries, down station, Fig. 28. For the reasons already detailed the following changes from the ordinary diagram (Fig. 26) are made, as indicated by the asterisks:—

Substitution of "S.C. key with switch" for ordinary D.C. key.
Line and earth reversed.
Batteries ,,
Galvanometer terminals ,,
Relay *coil* ,, ,,

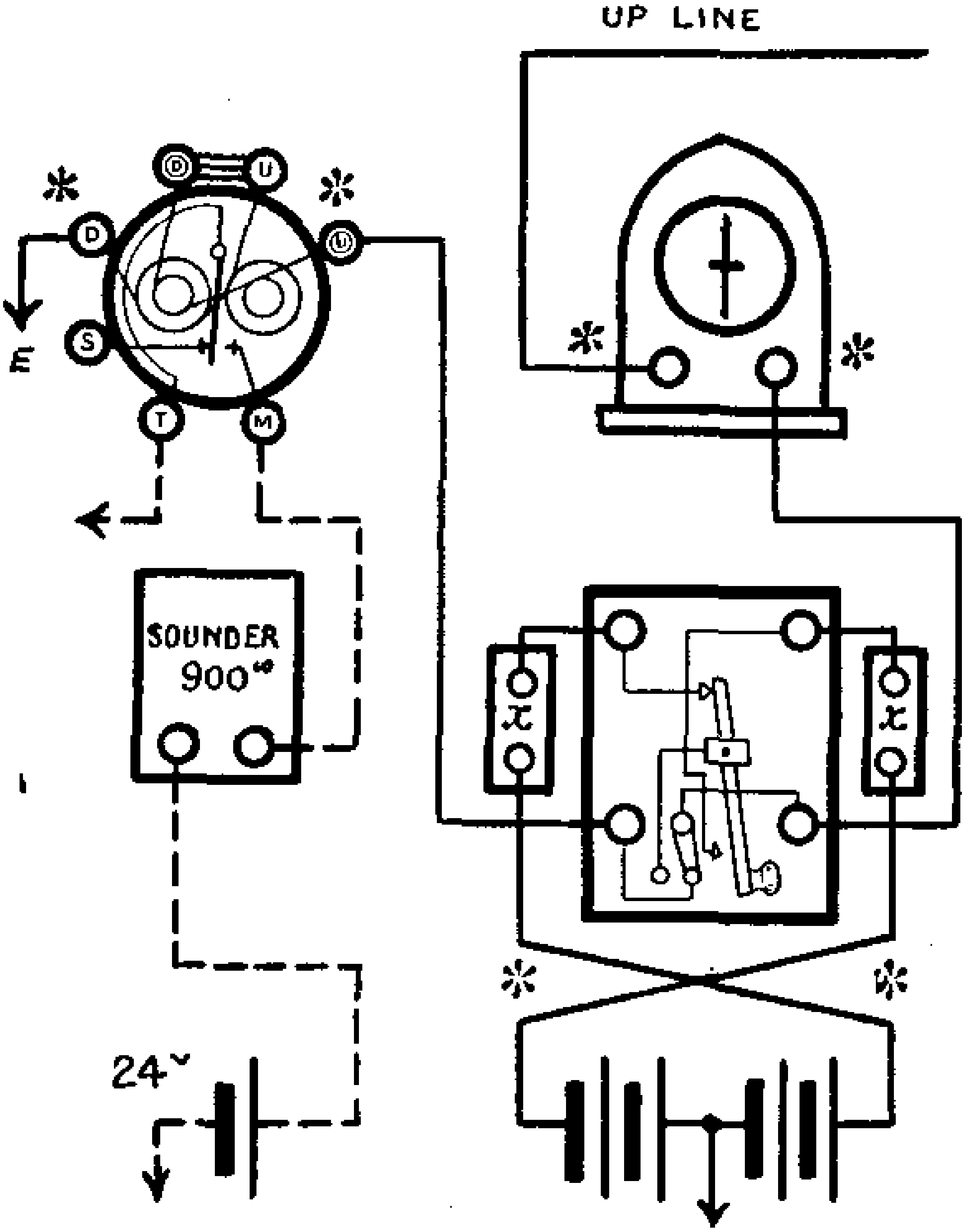


Fig. 28.—Double current: universal batteries, down station.

Double current: universal batteries, intermediate station, Fig. 29. This figure, for double current, corresponds with Fig. 25 single current. A galvanometer is inserted in the up line; if the resistances of the up and down lines are approximately equal the coil T will not be required. If, however, the

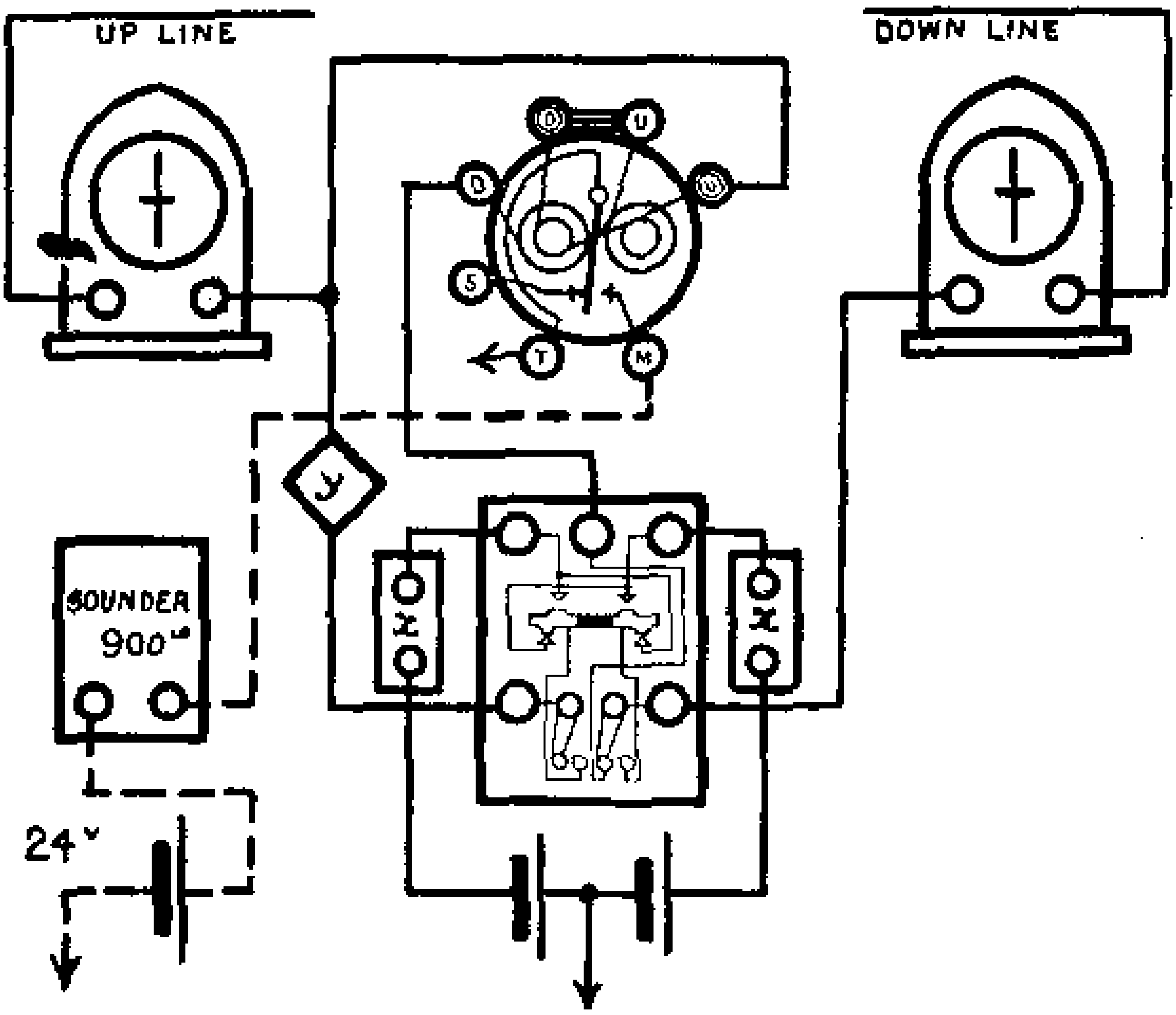


Fig. 29.—Double current: universal batteries, intermediate station (*a*).

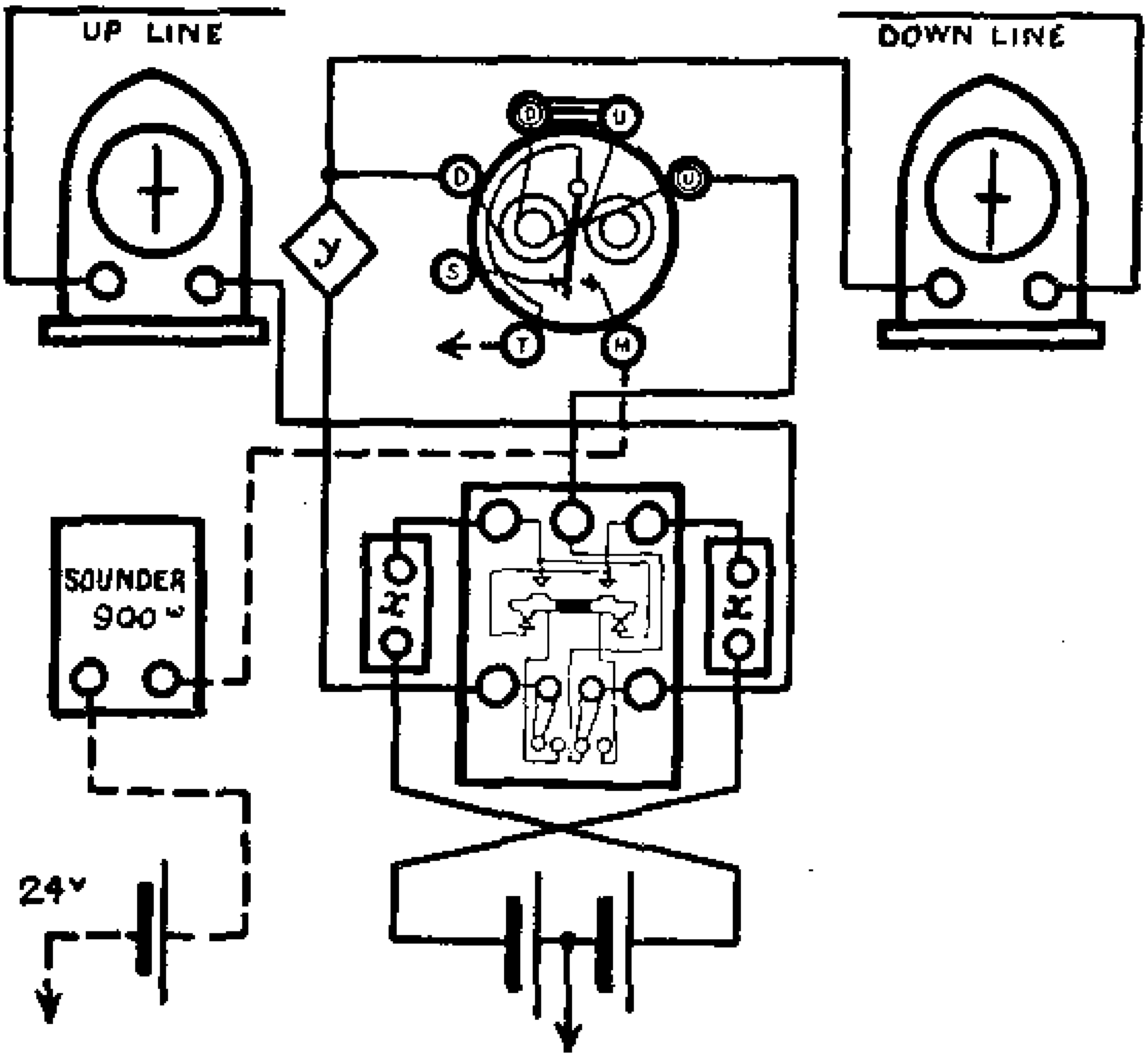


Fig. 30.—Double current: universal batteries, intermediate station (*b*).

lines be unequal, we cannot equalise them by using different values in the two metal-cased coils $x\,x$, as was done in Fig. 25, because each of these is in the up and in the down line alternately with the movement of the key. This diagram (Fig. 29) assumes the up line to be the shorter, and, therefore, needing a balancing resistance. This is placed as shown. If, however, the down line is the shorter, a good many alterations are necessary in order to bring the coil into this line, because it must not be in circuit to the received signals. These are shown in Fig. 30, and enumerated below :—

Resistance y must be put between left-hand front terminal of key and D of relay.
Down line galvanometer must be between down line and D of relay.
Up line must be taken from up line galvanometer to right-hand front terminal of key.
Middle terminal of key connected to (U) of relay.
Batteries reversed.

For detailed description of the single needle, sounder, &c., systems, see the author's *Elementary Telegraphy and Telephony*.

CHAPTER III.

DUPLEX TELEGRAPHY.

HAVING established a telegraph line between two centres, it is desirable to get the greatest possible amount of traffic through it, or to work it at the highest efficiency. One of the best known and most used plans for increasing the carrying capacity of a circuit is that of working it "duplex," by which means each station is enabled to send and receive at the same time. Clearly, some special arrangement of the apparatus is necessary, since by the depression of the key (or by the turning of the switch in double-current working) the receiving instrument is cut off. It is, therefore, arranged that the receiving portion of the apparatus is always in circuit, irrespective of the position of the key. Means have then to be devised by which the receiving instrument shall duly register the received signals, but shall be unaffected by those sent out. Two distinctive plans are employed to do this. In one the currents sent out to line pass through the receiving instrument, and would, therefore, work it, but a local current of similar strength is also caused to circulate in the receiver, but in the opposite sense or direction to the line current. Their effects being equal and opposite, the receiving instrument, though traversed by both, is unaffected. This state of things, however, lasts only so long as the distant station is idle. As soon as he sends, he upsets the balanced currents, and his signals are recorded by this upsetting. This is the "differential" plan.

The other is known as the "bridge" plan, so-called because the apparatus is arranged after the manner of the Wheatstone Bridge. The line currents in this system do not pass through the home instrument, and it is, therefore, unnecessary to pass a local current through. A local or compensating circuit, however, is arranged precisely as in the other plan, and the receiving instrument is placed in "bridge" between this and the line, so that the sent-out currents, in passing through the two circuits, produce equal *potentials* at the two ends of the receiving instrument (which in this case need not be differentially wound).

There is thus no tendency for a current to pass through the receiver. When the distant station sends, this equality of potentials is upset, current passes through the receiving apparatus, and signals are recorded.

DIFFERENTIAL DUPLEX.

Since two currents are to circulate in the receiving instrument, the latter must necessarily have two separate coils. Fig. 31 illustrates a simple bar of soft iron having two right-handed helices of insulated wire wound on it, so as to form two distinct circuits *a b* and *f g*. Two batteries are connected to these. The current in *f g* travels from the left-hand end of its helix, and would produce an N pole at the right of the core. The current in *a b* travels in the reverse direction, and would produce an N pole at the left. Assuming that the effects of the two currents are exactly equal, the bar will exhibit no polarity whatever, and if an ordinary soft iron armature were attached it would not be attracted. If, however, we upset this state of balance, the core will no longer be inert. Suppose that the battery in *f g* is increased. The effects of this winding will now be greater than those of *a b*, and the excess will produce an N pole at the right. If we increase the battery in *a b* over that of *f g*, its excess will produce opposite polarity. Again, starting from the state of equilibrium, if we break either circuit *a b* or *f g*, the remaining coil will energise the core and attract the armature—that is, whenever we upset the balance of currents circulating round the core, the latter is excited.

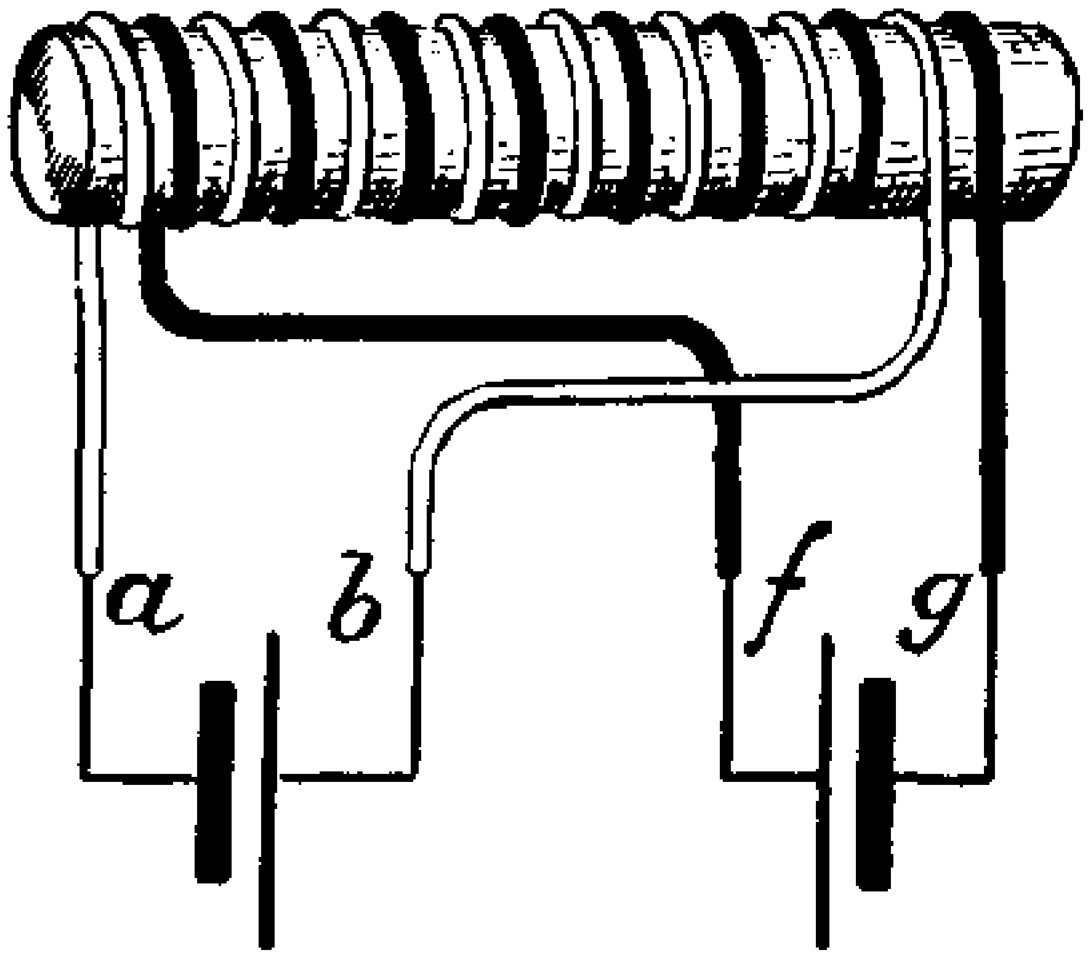


Fig. 31.—Principle of differential winding.

We have shown two separate batteries connected to the coils, and have assumed that their effects are equal. But this separation is unnecessary. If we employ a single battery, we shall apply an equal E.M.F. to both coils automatically. In order that the currents in both may be the same, the resistance of the two wires must be equal, and since equal currents pass through them, the magnetic effects of both must be made equal. This is effected by using two precisely similar wires, and by winding them together, as shown in the figure, so that each complete winding occupies a similar position with regard to the core. Such coils are *differentially* wound.

Coming now to Fig. 32. We have at X the core with its two

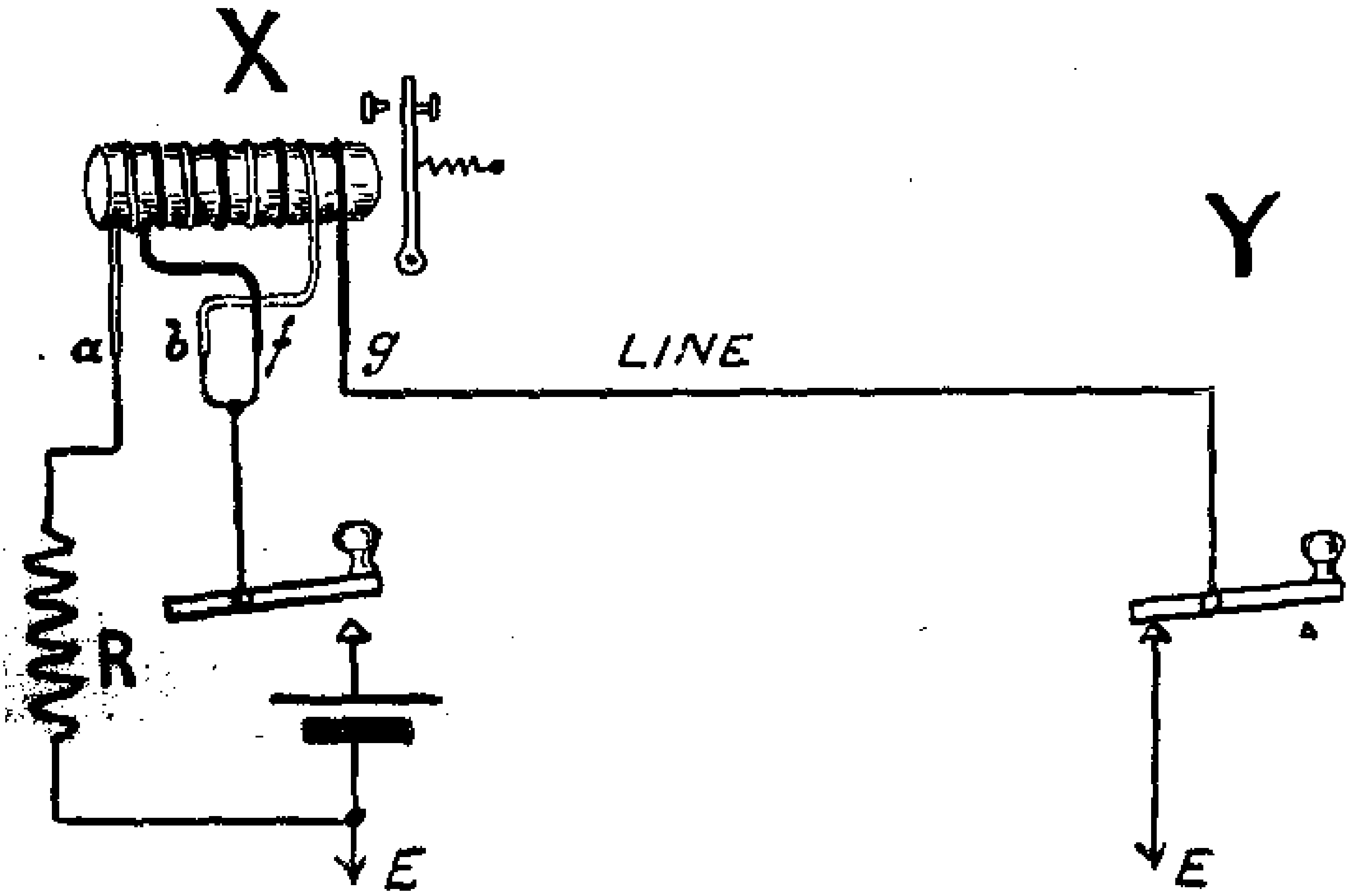


Fig. 32.

windings. The ends *b* and *f* are connected together and to the sending key. The end *g* is joined to the line, which at the distant station Y is connected to another key whose back stop is to earth. The end *a* of coil *a b* is taken, at its own station, through a resistance exactly equal to the line, and thence to earth.

If the key at X be depressed, the battery has two paths open to it, one through the winding *b a*, resistance coil, and earth—termed from its function the compensation circuit—the other, through *f g*, the line, and distant station's key to earth. As these two paths are equal in resistance, the currents will be equal. But the two currents are traversing the coils of the electro-magnet in opposite directions, and therefore nullifying each other's effects there—that is, station X is sending, but his own receiving apparatus, represented by the differentially-wound core, is not affected.

Now, assuming the key at X to be permanently held down, and the electro-magnet unaffected, it will easily be seen what effect will follow if the key at Y be depressed. The line, instead of being to earth through the back stop of the key, will be disconnected, and the path through coil *f g* no longer complete for the battery at X. The current in this winding is therefore stopped. But the circuit through *a b* is still available, and the current flowing therein is now free to energise the core.

We have shown no battery at Y. In practice, a battery similar to that at X would be used, and this could be connected with either its positive or negative pole to line. If the former, then exactly similar results would follow to those we have shown above. With the key at X permanently down, the depression of that at Y brings into the line circuit a second battery, equal to the first, but with its E.M.F. acting in the reverse direction. That is, as before, no current flows in the line circuit, and the *electro-magnet at X is energised by the compensating current in a b.* If the negative pole be connected to Y's key, then when both keys are down the two batteries combine their effects in the line circuit, and the current therein is increased to twice its former value. The electro-magnet is therefore traversed by a current of a certain normal strength in coil *a b*, and by one of double that value in coil *f g*. The latter, therefore, actuates the electro-magnet. Both these effects, of augmenting and opposing batteries, occur in practice.

Fig. 33 gives the theoretical arrangement of the two stations. There are three distinct circuits:—(1) The line circuit, made up of the line itself and the line coils of the electro-magnets at X and Y; (2) the compensation circuit at X; and (3) the compensation circuit at Y. The currents in these are termed—(1) the line, and (2 and 3) compensation currents respectively. Assuming that the batteries have no resistance, it will be seen that either or both can be brought into the line circuit, but each has access to its own compensation circuit only.

When X's key is held down, the line current passes to earth at Y through *one* coil of the electro-magnet and the back stop of the key. Y's key being at rest, there is no balanced state of currents in Y's electro-magnet, and the latter is worked by X's current in *the usual manner. With X's key still down, the depression of*

Y's brings into the line circuit a second battery whose E.M.F. is added to the first. The line circuit is thus traversed by a current of double the normal strength, and both electro-magnets are energised.

If the batteries have no resistance, as we have assumed, the back stop of the key is connected direct to earth, as shown in Fig. 33. The received current, on arriving at the point *f*, passes direct to earth whether the key at the receiving station be up or down. In the former position it passes through the back stop, and in the latter through the front stop and battery—regarding the latter as a *path* or portion of the circuit, irrespective of its E.M.F. But battery resistance is, of course, inevitable, and even where secondaries are in use, with their practically negligible resistance, protective coils are inserted which become (for our purpose) equivalent to battery resistance. Hence between the front stop and earth there is invariably some resistance, and in order to balance this, so that the resistance of the circuit shall not vary with the movements of the apparatus, an equalising coil is placed between the back stop and earth. Under these conditions, when the received current arrives at *f*, it has before it two paths—one through the resistance coil, and the other through the compensation circuit, to earth. The resistance of the latter is very high compared with the former, so that practically the whole of the received current passes through the back

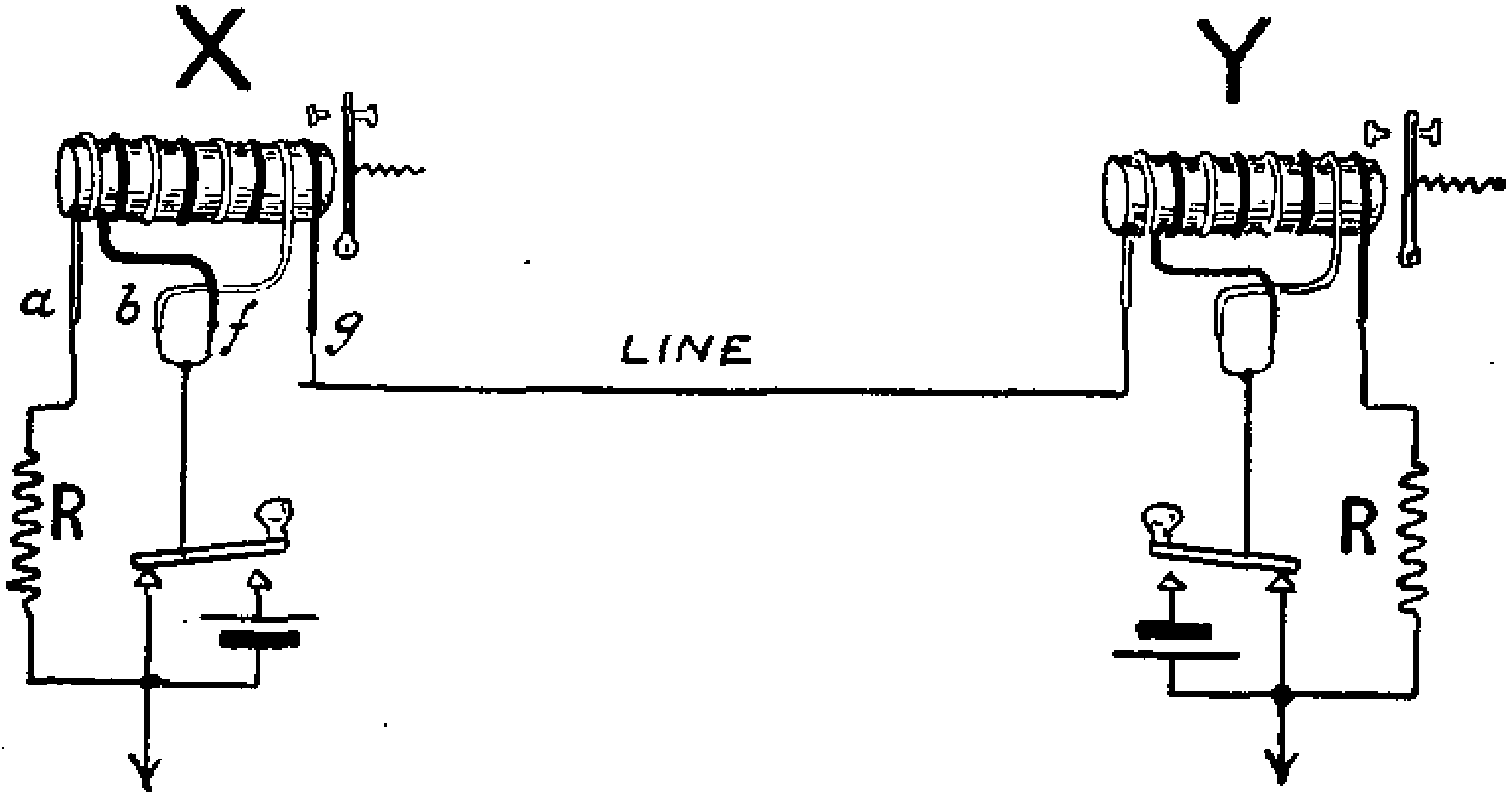


Fig. 33.—Theoretical duplex circuit.

stop. The effect, however, of this equalising coil is to shunt a small portion of the received current through the compensation circuit. In traversing coil *a b* of the electro-magnet, this small current is in the same direction as that in the line coil, so that its effect is added to that of *f g*. The receiving instrument thus gets the full value of the received current, irrespective of the path it takes. This is easily seen with one key only depressed, but similar effects occur when both are down.

In addition to the two key-positions just considered, there is a third, when the lever is moving from one contact to the other. The time occupied in transit is very short, but whilst it lasts earth is entirely cut off from the key. The distant station's key being down, the received current has then to pass through the compensation circuit to earth. During this period the resistance of the line circuit to the sending battery is thus double the normal, and the line current is reduced to one-half. At the receiving end this reduced current passes through *both* coils of the electro-magnet and in the same direction, so that its effects are practically the same as usual. At the sending end, which we will assume to be Y, the balance is upset, but as this disconnecting action of X's key merely precedes the full depression of the latter, it (theoretically) lengthens the signal about to be sent.

With a key and contacts of the pattern shown, the lever must necessarily leave one stop before making connection with the other. But with differently arranged contacts—the latter being flexible, so as to follow to some extent the movements of the lever—it is easy to cause the new contact to be made before the old is broken. By this plan the battery is practically short-circuited during the brief interval that the lever is touching both stops, and the doubling of the resistance to the distant station's battery is avoided. In all double-current keys the contacts are now made adjustable, so that the key in its journey may be arranged to cause a disconnection or to short-circuit the battery at will. In duplex working, however, the keys are allowed to disconnect as described. The duration, both of the break and of the short-circuit, should, of course, be made as brief as possible.

Compensation Circuit—Rheostat.—We have indicated the resistance of this circuit by a coil of fixed value, but it will readily be understood that the resistance of the line is by no means a fixed quantity. The conductor-resistance of the wire itself is not constant, but varies with the temperature; whilst the insulation is subject to still greater changes, due to weather, &c. Hence, the resistance which balances the line must be capable of adjustment. It may consist of a set of ordinary resistance coils of suitable values, but is generally a rheostat or box of coils, any number of which may be thrown into circuit by the movement of an arm or arms. The latest form of rheostat is

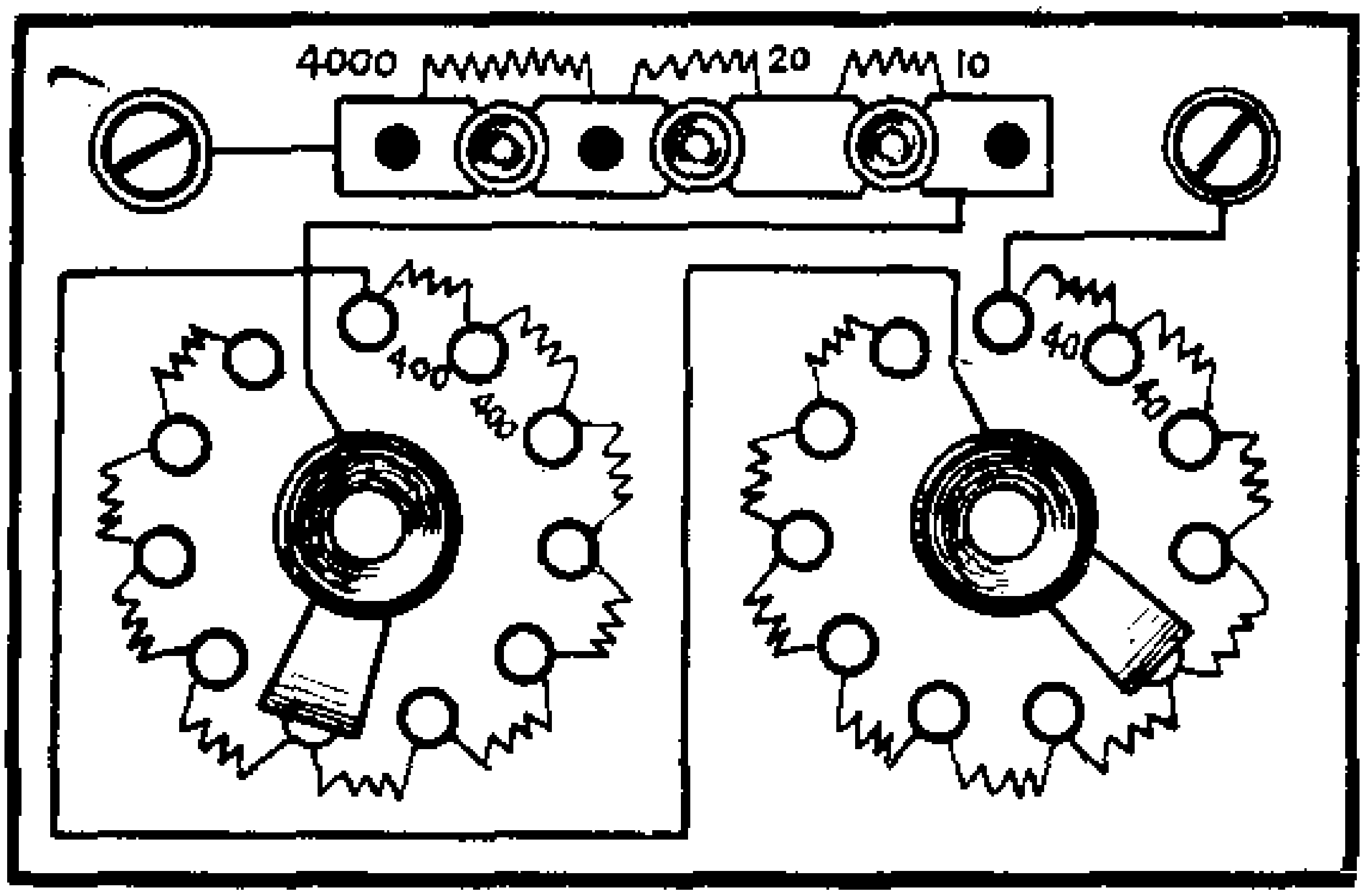


Fig. 34.—Diagram of rheostat.

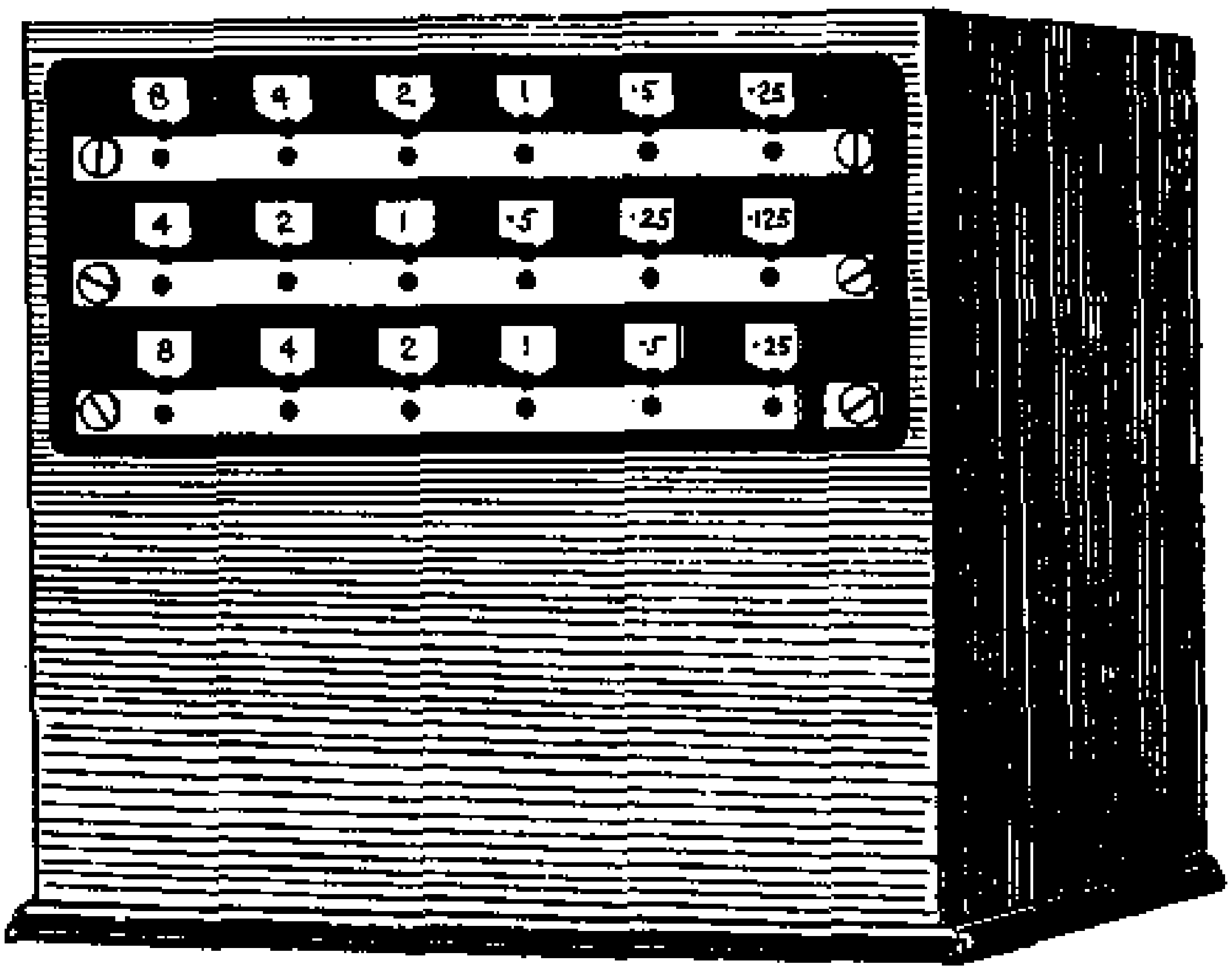


Fig. 35.—Triple condenser.

ebonite top are mounted the movable arms and contact studs. The top is illustrated in Fig. 34. Two sets of studs are arranged in circles, those on the right having a coil of 40 ohms and those on the left a coil of 400 ohms between each pair of studs. Three supplementary coils are provided of 10, 20, and 4,000 ohms, which are brought into circuit by the removal of the plugs. Any resistance from 10 to 8,430 ohms can therefore be introduced by gradations of 10.

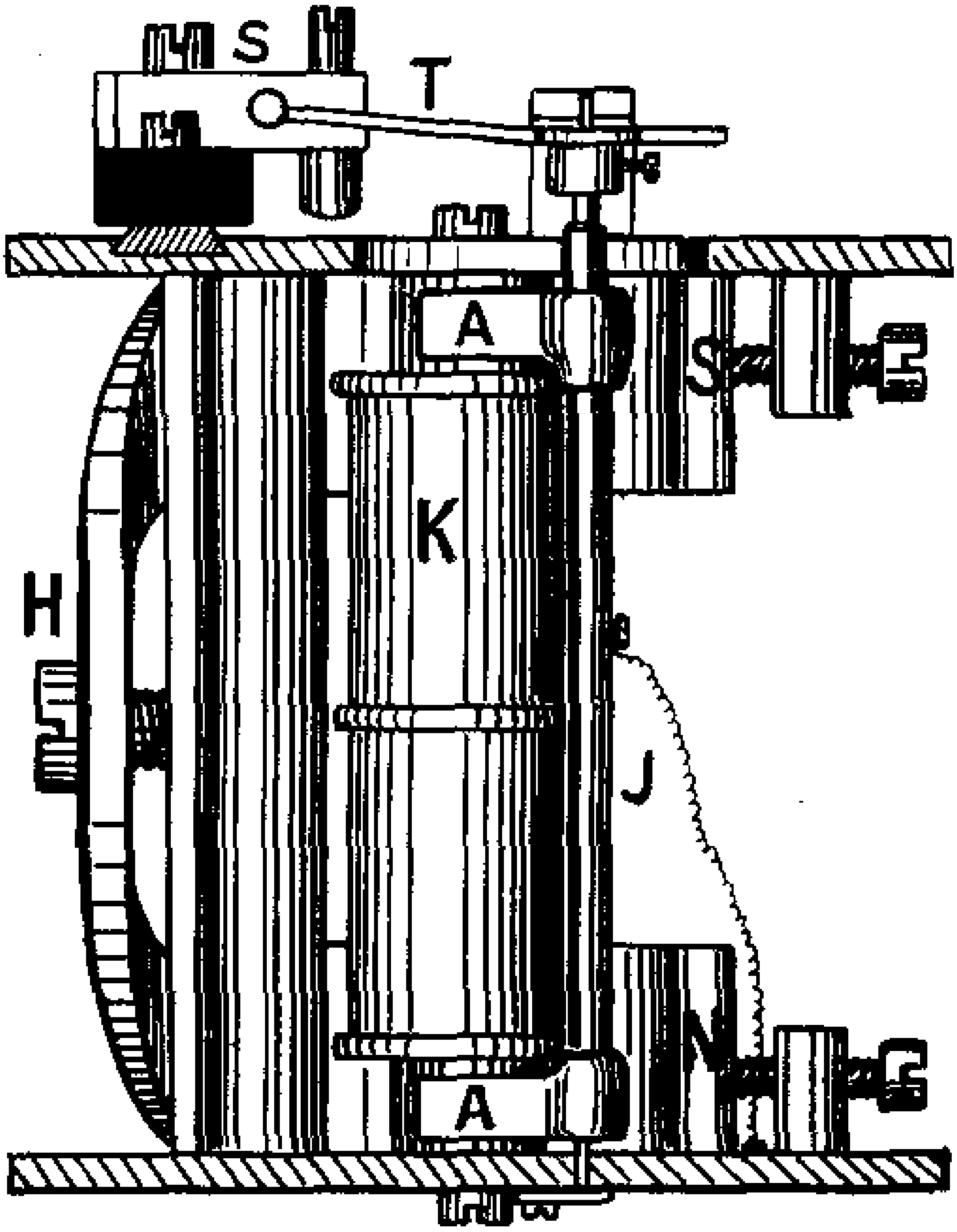


Fig. 36.—Standard polarized relay.

Compensation Circuit—Capacity.—With lines of considerable length the effects of capacity begin to be felt, and have to be balanced. A condenser, in series with a resistance, is then placed across the rheostat. Both are adjustable, the condenser in order that the capacity may be adjusted, and the resistance in order that the charge and discharge may be slowed down to the requisite degree. In some cases the distribution of capacity in the line requires that the condenser shall be divided, the second portion receiving its charge through a second timing resistance, as well as through the first. Other long circuits containing a submarine cable may require the condenser to be in three sections, with suitable retardation coils. Such a condenser is illustrated in Fig. 35.

Differential Galvanometer—Balancing.—The adjustment of the compensation circuit is effected with the aid of a differential galvanometer, an instrument of the ordinary vertical pattern, but provided with two windings in a similar manner to the core of Fig. 31. With equal currents circulating in both coils the needle is unaffected, but any difference in the currents will result in a deflection. After the rheostat has been correctly adjusted, the capacity may cause momentary deflections on the depression and release of the key, and the condenser and its retarding coils have then to be adjusted till these "kicks" of the needle disappear.

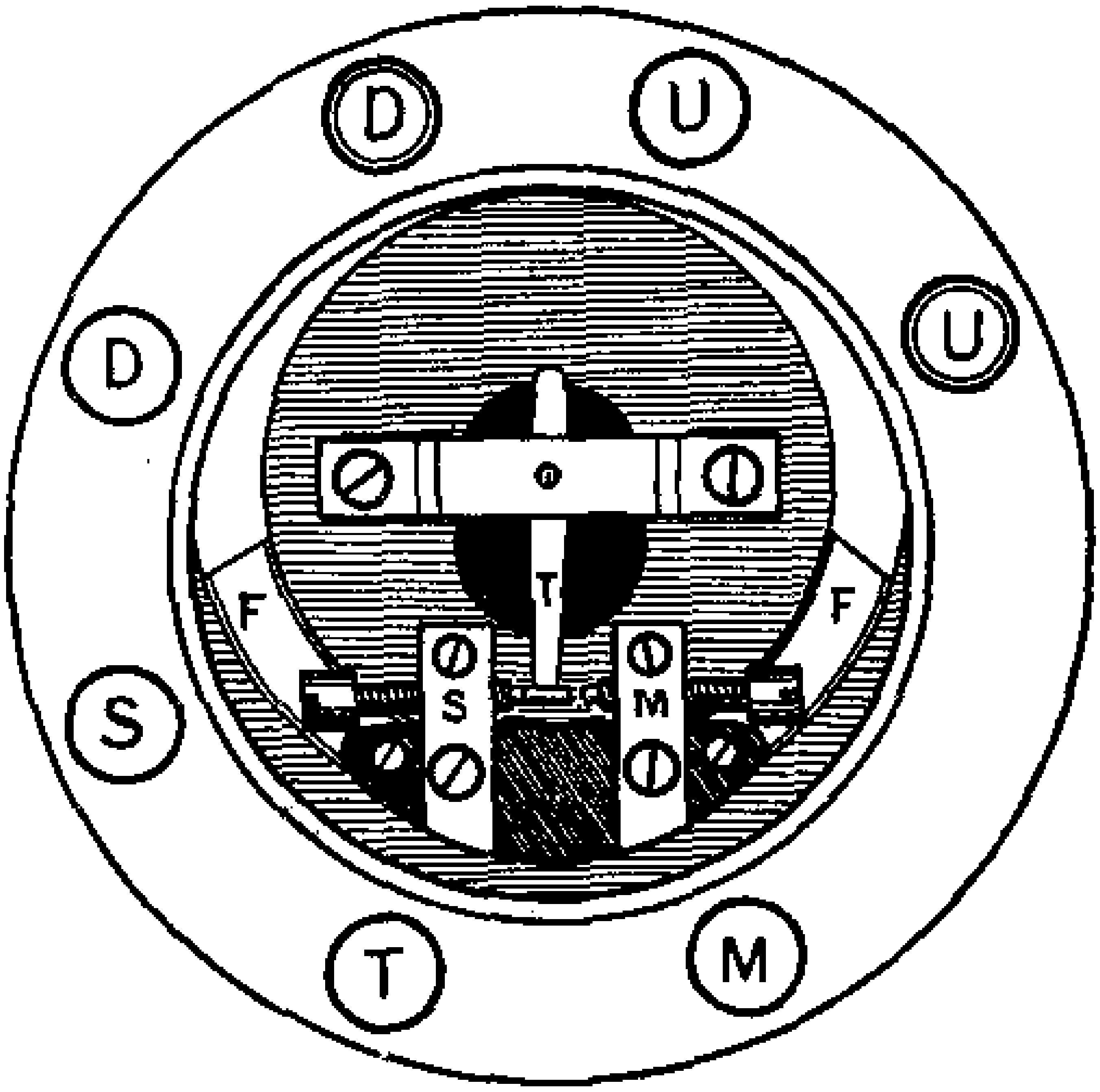


Fig. 37.—Standard polarized relay: plan.

Standard Polarized Relay.—The instrument commonly employed in the place of the theoretical electro-magnet of Fig. 33 is the standard polarized relay. Fig. 36 gives a section of the interior, Fig. 37 a plan, and Fig. 38 shows the arrangement of the cores and armatures.

Two bar electro-magnets K are placed vertically between the base and upper plate. One of these is omitted from Fig. 36 in order to show the armatures. On a brass spindle J are fixed two soft-iron tongues or armatures A A, so that their free ends may play between the two pairs of poles. The tongues are magnetised by the presence of a horse-shoe magnet H curved as shown, so as to bring it within the cylindrical case of the instrument. At its upper extremity the brass spindle carries a German-silver tongue T, furnished with a platinum contact piece, which plays between the ends of two screws S and M (Fig. 37), also provided with platinum tips. The ends of one coil or winding are brought to the terminals U and D, and the ends of the other to (U) and (D), and the winding is such that if a current passes in the direction U to D (either coil) it will develop an S pole at the top and an N at the bottom of the left-hand electro-magnet, and reverse polarity in the right-hand one. The tongues being S at the top and N at the bottom, the armature system will move to the right and make contact with the stop M. A current in the reverse direction will, of course, move the tongues to the stop S. These two stops are connected to similarly-marked terminals, whilst the tongue and armature systems are naturally in contact with the framework, which is connected to terminal T. To ensure the connection between the spindle ends and the frame, they are further joined by a spiral of very fine bare wire, as seen in Fig. 36. The sounder and battery are brought to terminals T and M, so that the movement of the tongue to the latter stop completes the local circuit. Hence the labelling, M = marking, S = spacing.

The carriage on which the two stops are mounted is fixed to the arc-shaped piece F, the latter being movable in a slot cut in the upper plate. It is kept to the left by the tension of a spring, and is brought to the right by the action of an adjusting screw. When the carriage is in the centre, the movement of the tongue to the right carries the armatures beyond the centre line, so as to be nearer the right-hand pole pieces. The tongue will, therefore, remain on that side. If it is pushed to the left, it remains there for a similar reason. If, however, the carriage be moved to the left, so that the armatures when moved to the M stop are still on the *left* of the central line, they will return to the S stop on the cessation of the current. The instrument has then a "spacing bias." This is clearly necessary in single-current working, in order that the local circuit may be broken when the key returns to its back-stop. With the carriage to the right, we naturally give the instrument a "marking bias." By putting on a bias, however, we detract from the sensitiveness of the relay, hence double-current working, which allows the carriage to be in its central position, utilises the maximum of sensitiveness.

Fig. 38 shows the arrangement of the cores and armatures. Each core C is turned up from a rectangular bar of sufficient cross-section to form the pole pieces. The portion between these is then turned down to the required diameter. Each core is thus a single piece. The best Swedish iron is used, and when the shaping is completed the core is very carefully annealed, after which process no further tooling is permissible. A split bobbin is then fitted to take the coils. This bobbin has a central as well as the two end cheeks. By this device only half a coil need be unwound to get at a fault, and further, by starting the winding in the centre and working towards the outer cheeks, the ends of the coil (or coils, as it is differentially wound) are both *outer* ends, a great advantage in case of a broken end.

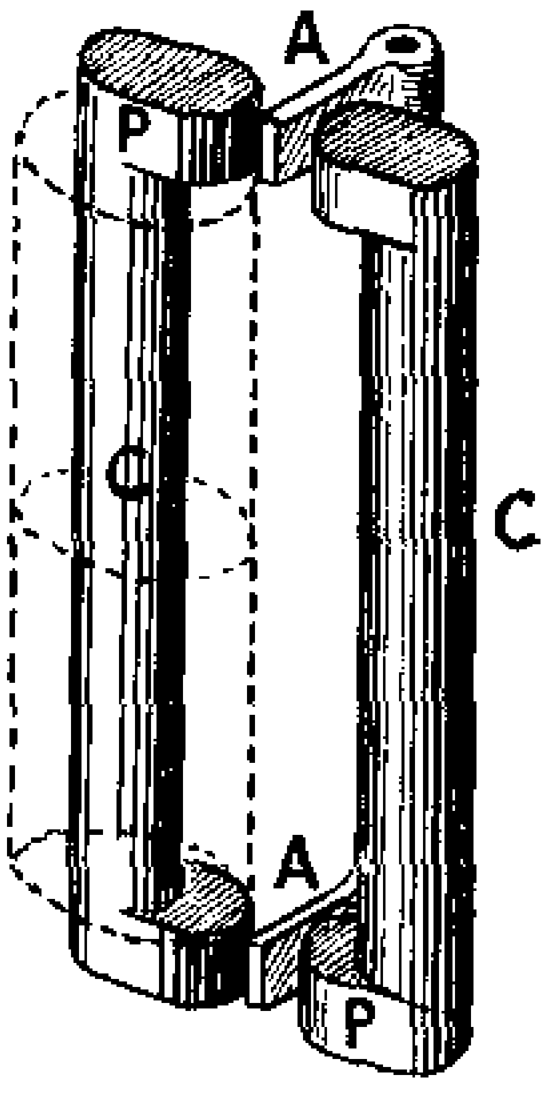


Fig. 38.—Arrangement of cores and armatures.

Actual apparatus in use. Having treated of the principal pieces of apparatus, we have to consider their grouping as a whole. A complete set for single-current duplex working is shown in Fig. 39, and comprises key, differential galvanometer, differential relay, rheostat, battery-resistance coil, and sounder. In order that the circuit may be worked simplex at will, a switch is added by which the necessary alteration is made in the connections. Fig. 40 gives the "duplex" position in skeleton.

In Fig. 41 both stations, X and Y, on a duplex circuit are shown, both keys being depressed. Starting from Y's key, the positive pole of the battery is applied to the split at the galvanometer. As the circuit is balanced, the current divides equally. The portion going to line enters X's relay, passing through it from (U) to (D), then through X's battery (the key being down) and line coil of

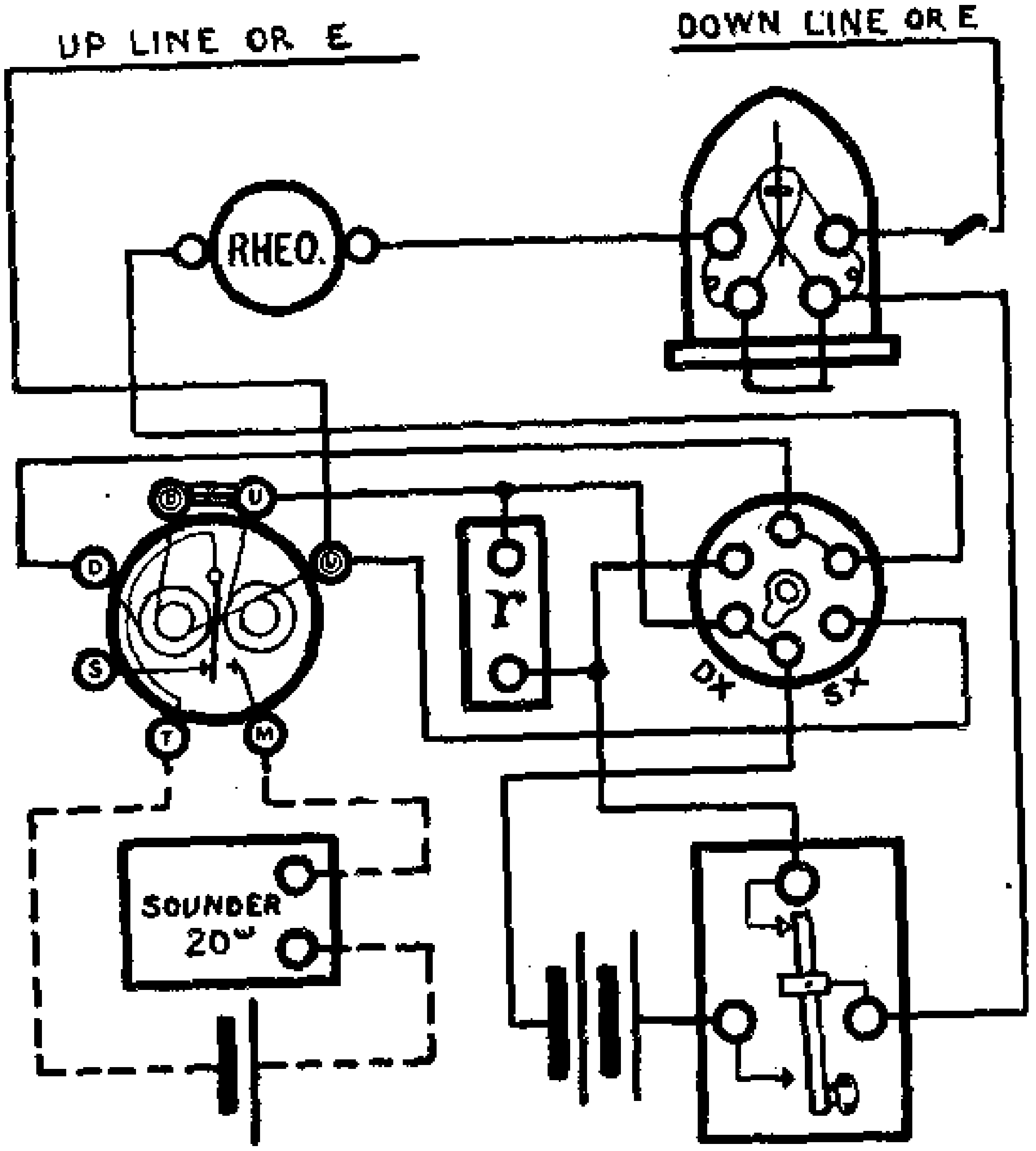


Fig. 39.—Single-current: duplex or single.

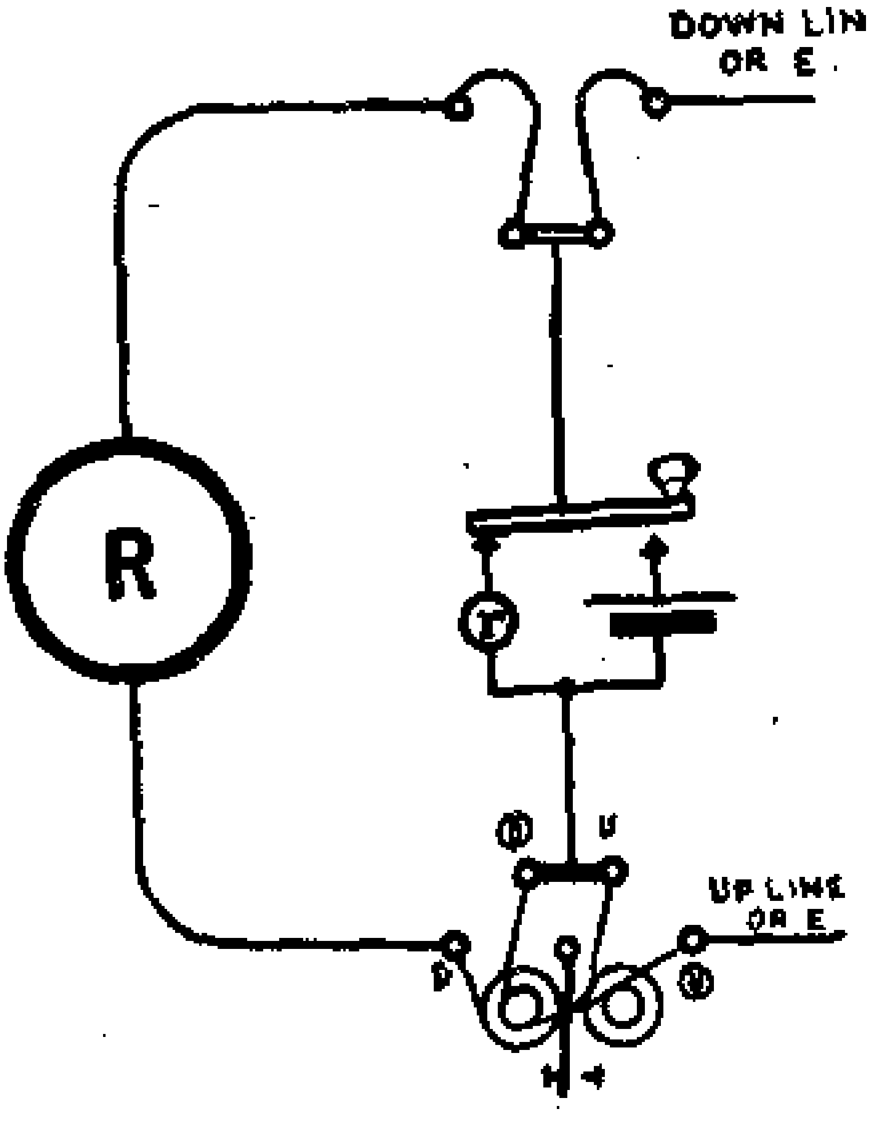


Fig. 40.

through the line coil of the home relay (similar coil to that at X) and back to the negative pole of the battery. The other moiety of Y's current passes through the compensation coil of galvanometer, rheostat, and other coil of relay. The same actions take place if we consider the circuit from X.

It will be seen that the current in the line coils of galvanometer and relay at the home station tends to deflect the needle to the right and to move the relay tongue to marking. That in the compensation coils has the opposite tendency. But both batteries are acting in the line circuit and are assisting each other. Therefore, the current in the line coils of the instruments at both stations is practically twice the strength of that in the compensation coils. Hence, both needles deflect to the right (marking) and both relay tongues move to marking, thus actuating the sounders. The arrows in the diagram indicate the direction and the comparative values of the current in the different parts of the circuit.

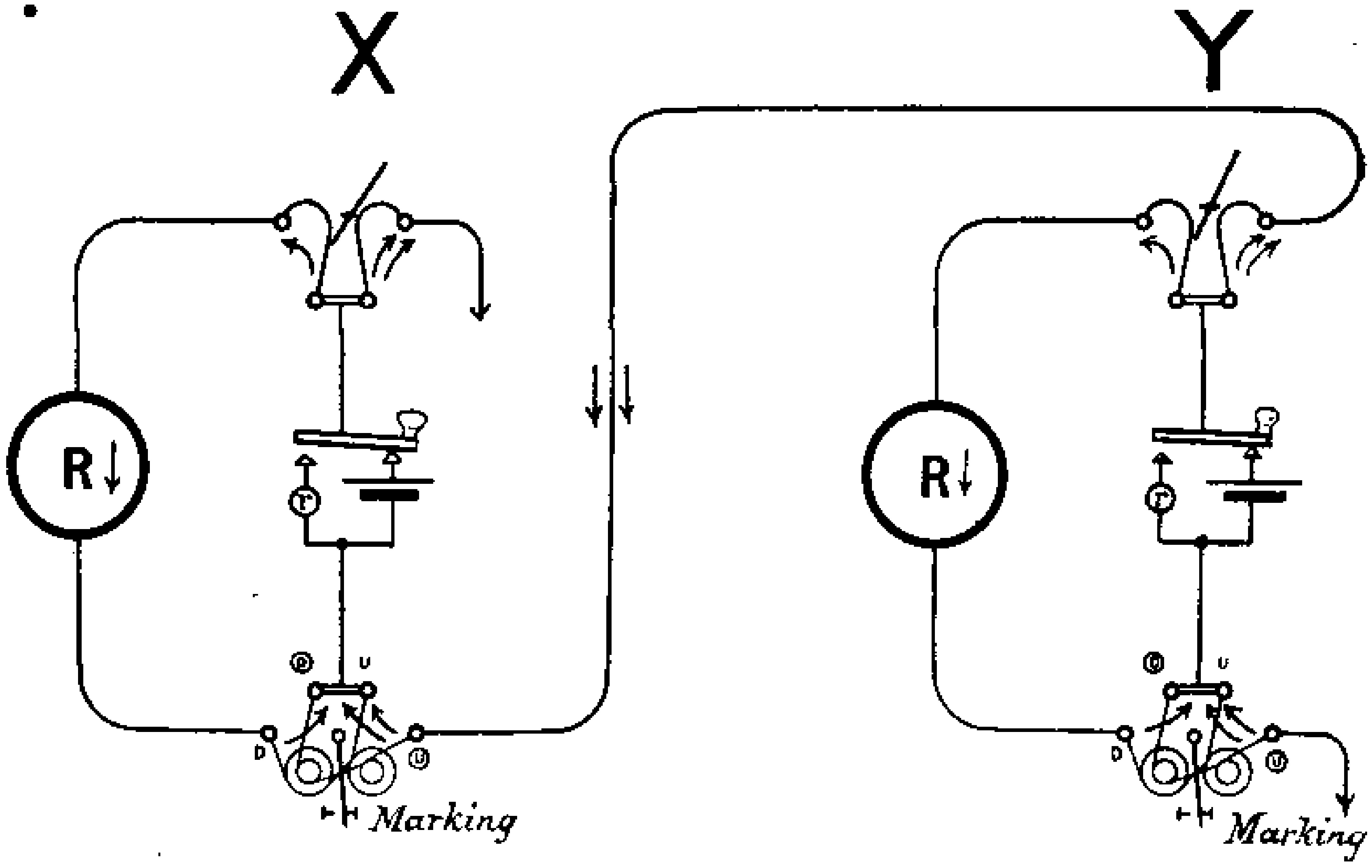


Fig. 41.—Single-current duplex: both keys depressed.

Double-current Duplex.—Duplex working on the single-current system is now falling into disuse, all new circuits being worked double-current. The only change is the substitution of a double-resistance coil naturally disappears. In Figs. 42 and 43, however, the latter key is shown, for simplicity's sake, with an additional battery on the back stop. Two batteries, of course, are not used in practice, a single battery being reversed by the action of the double-lever key.

Fig. 42 shows the circuit with both keys at rest. This is precisely the same as Fig. 41, with one exception—that the current in all parts of the circuit is reversed in direction. Thus both galvanometer needles are deflected to the left and both relays are to spacing.

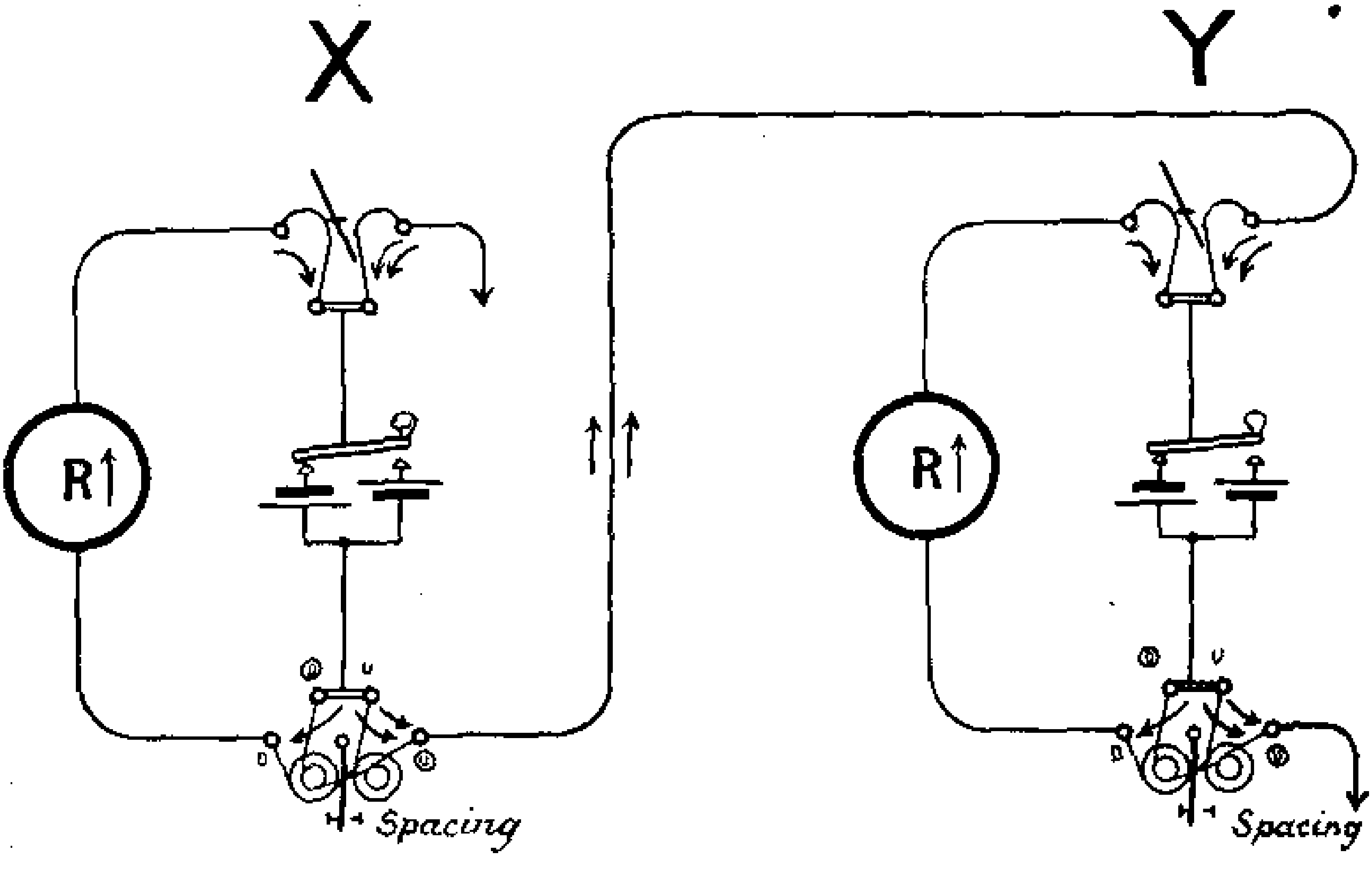


Fig. 42.—Double-current duplex: both keys at rest.

In Fig. 43 the key at one station is at rest whilst the other is depressed. Obviously the two batteries are, therefore, opposing each other and no current flows in the line circuit coils. The instruments at both offices are traversed by their respective compensation currents only. At X this current is in such a direction as to deflect the needle to the left and to keep the relay to spacing, and this is what is required, as Y's key is at rest. At Y the compensation current is in the reverse direction, and deflects the galvanometer needle to the right and causes the relay to mark. This, again, is what is required, X's key being depressed.

The full connections of a double-current, duplex or single set, are given in Fig. 44, primary batteries being employed.

When secondary batteries are in use, the alterations shown in Fig. 45 are necessary—this being for an up station. Two earthed batteries being employed, a single-lever key is necessary, provided with a switch for use in single working. The coils x x are metal-cased. The sounder is a 900-ohm one, 24 volts being employed to actuate it, and the relay terminal T is earthed.

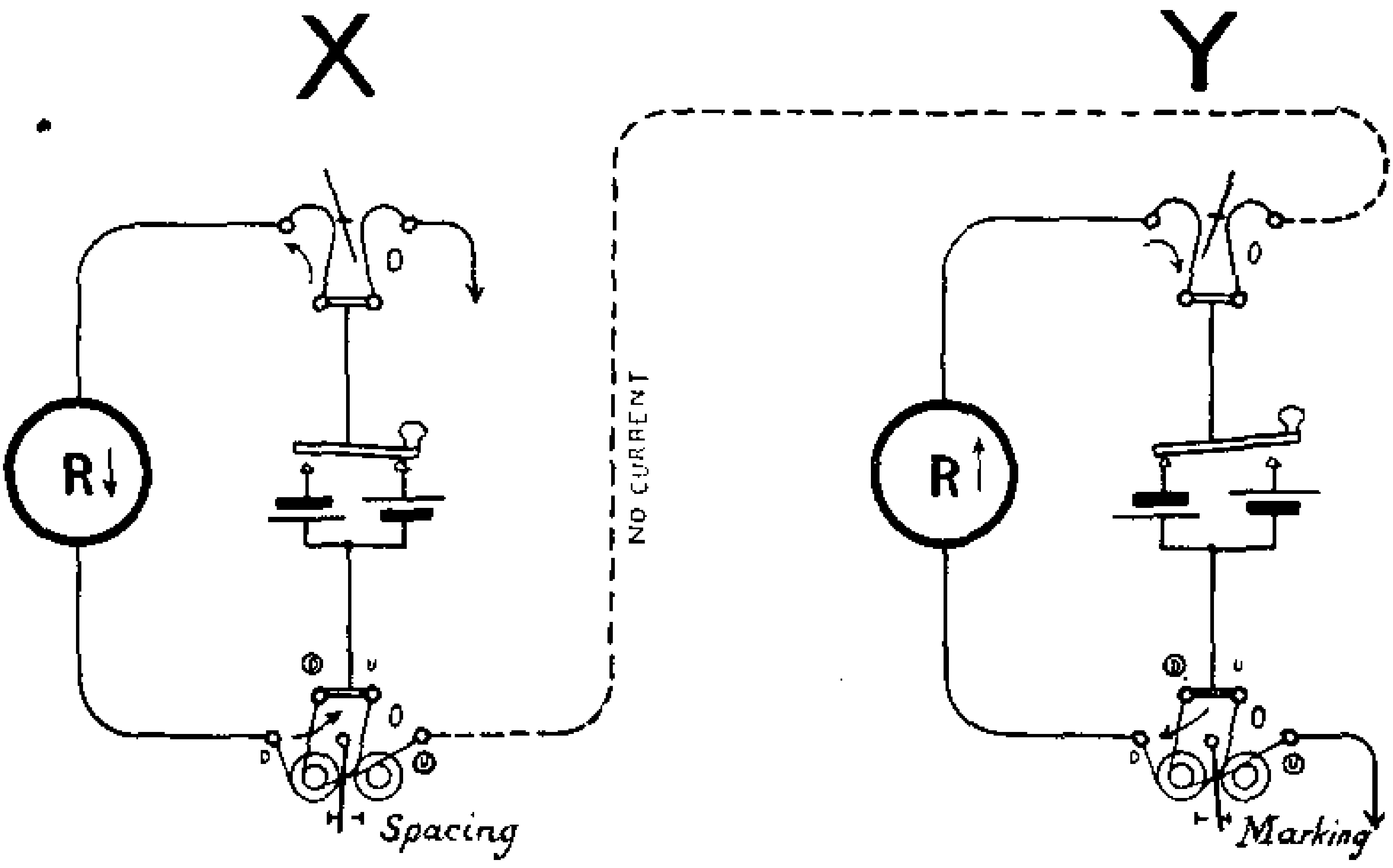


Fig. 43.—Double-current duplex: one key up, one down.

For a down station worked by secondaries the following alterations to Fig. 45 are necessary:—

Connections on upper terminals of galvanometer reversed.
Connections on lower terminals of galvanometer reversed.
Batteries reversed.
Connections on D and (U) of relay reversed.

In America the single-current system is known as the Stearns duplex, and the double-current the "polar" duplex. The break at the third position of the key is avoided by the use, in the first case, of a "single-current transmitter," and, in the second, of a "pole-reverser" (see Figs. 183 and 184). The sending key then simply completes the circuit of the working coil. As we have seen, it is comparatively easy to arrange that the of the key itself shall short-circuit instead of disconnecting, but it has not been found necessary in duplex working in this country to avoid the disconnection.

Bridge Duplex.

The E.M.F. of a battery is equivalent to the difference of

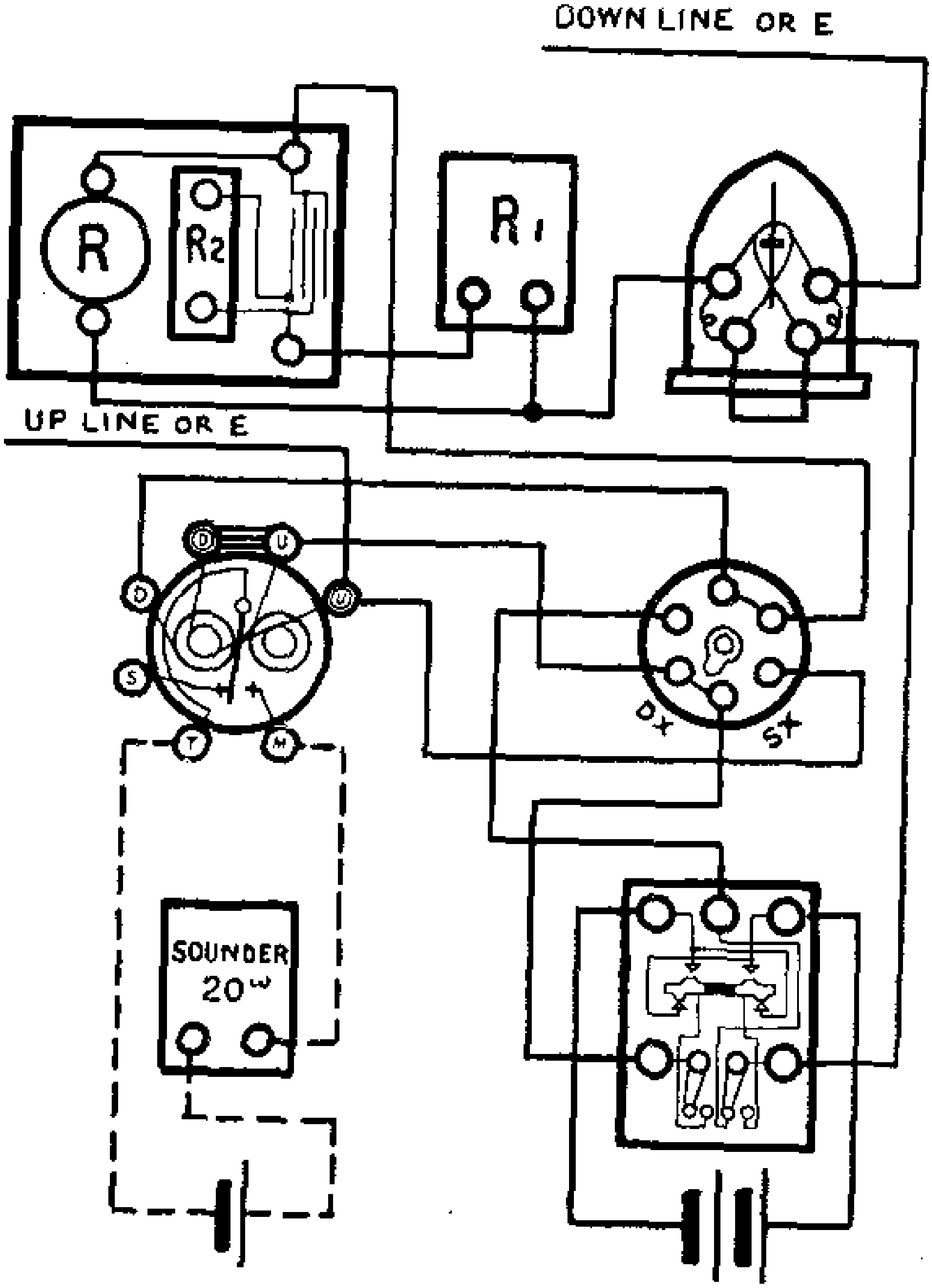


Fig. 44.—Double-current: duplex or single, primaries.

potential, or electrical level, between its poles. That is, with a battery having an E.M.F. of 50 volts, the positive pole is that amount above the negative. It is usual to regard the earth as zero, and that pole which is earth-connected is at zero potential.

If the negative pole of our battery is to earth, the positive will be 50 volts above it, or +50. If the positive pole is to earth, it will be at zero, and the negative 50 volts below it, or −50. If the centre of the battery be to earth, the positive pole will be 25 above, and the negative 25 below, zero, or at +25 and −25

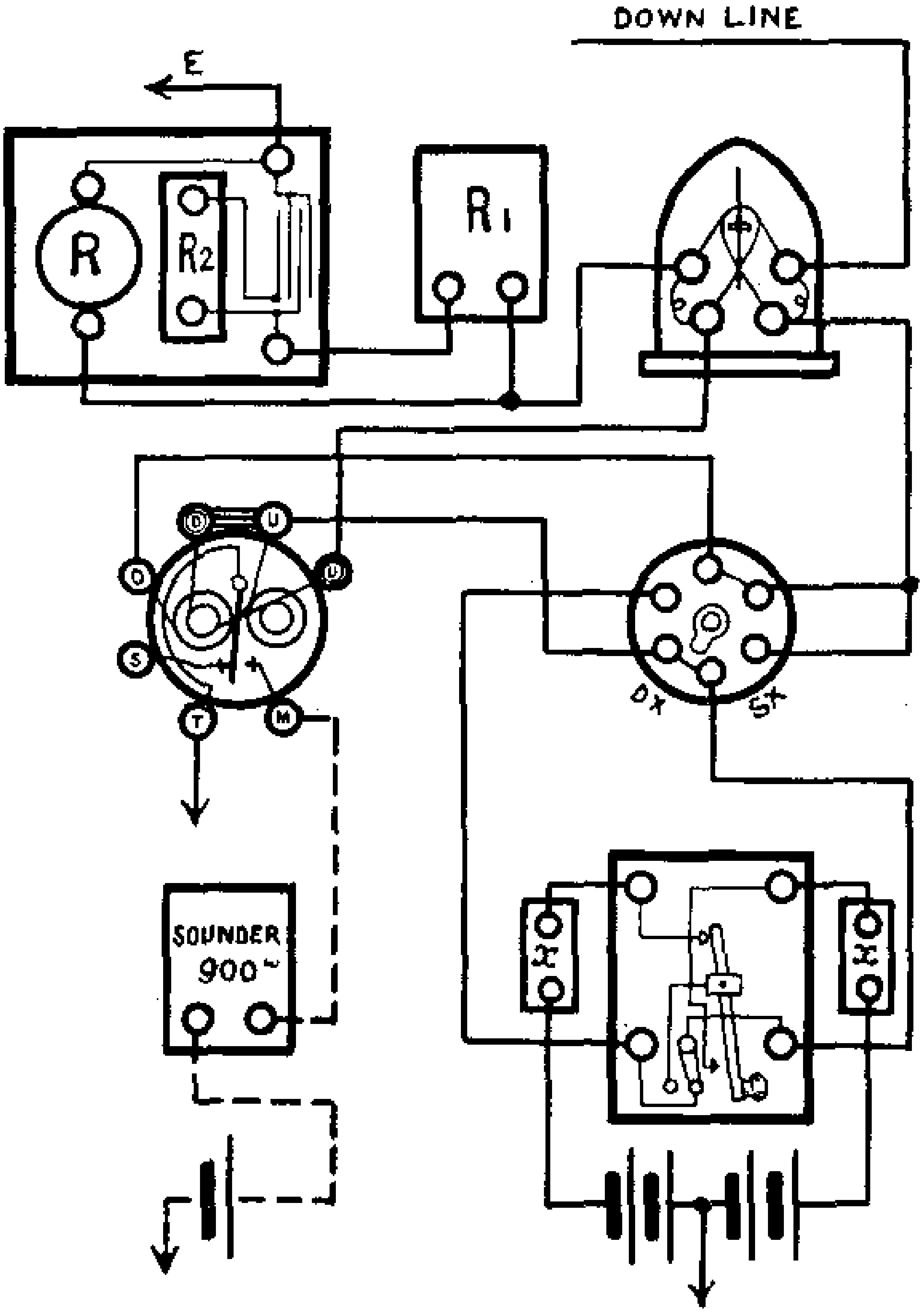


Fig. 45.—Double-current: duplex or single, universal batteries, up station.

respectively. However regarded, the available E.M.F. is unaltered —viz., 50 volts.

Assuming that the battery resistance is negligible, the effect of connecting it up to a larger or smaller resistance will be to draw from it a smaller or larger current, but in both cases the E.M.F. at the terminals of the battery will remain unaltered. Imagine it to be connected to a bare wire of considerable resistance and of uniform cross-section. Then since the positive pole is at a higher potential than the negative and they are connected by the wire, it is clear that the potential must *fall* along the wire, from its maximum at the positive to the minimum at the negative pole. This is quite irrespective of the actual resistance or length of the wire. At a point, therefore, a quarter of the length from the positive pole, the potential will have fallen a quarter of the whole; at a point half-way along the wire it will have fallen one-half, and so on. At these points it will be 37·5 and 25 volts respectively.

If instead of a single wire we connect two wires to the battery, in parallel with each other—of equal or unequal resistance or length—obviously the potential will fall in a similar manner through both. At a point half-way along one the potential will be the same as at a point half-way along the other—viz., 25 volts. If, therefore, we bridge these two points by a galvanometer no deflection will result, because there is no E.M.F., both ends of its coil being at the same potential. Any other pair of points could be taken, so long as they are the same fraction of the distance from the same pole, and the same result will follow.

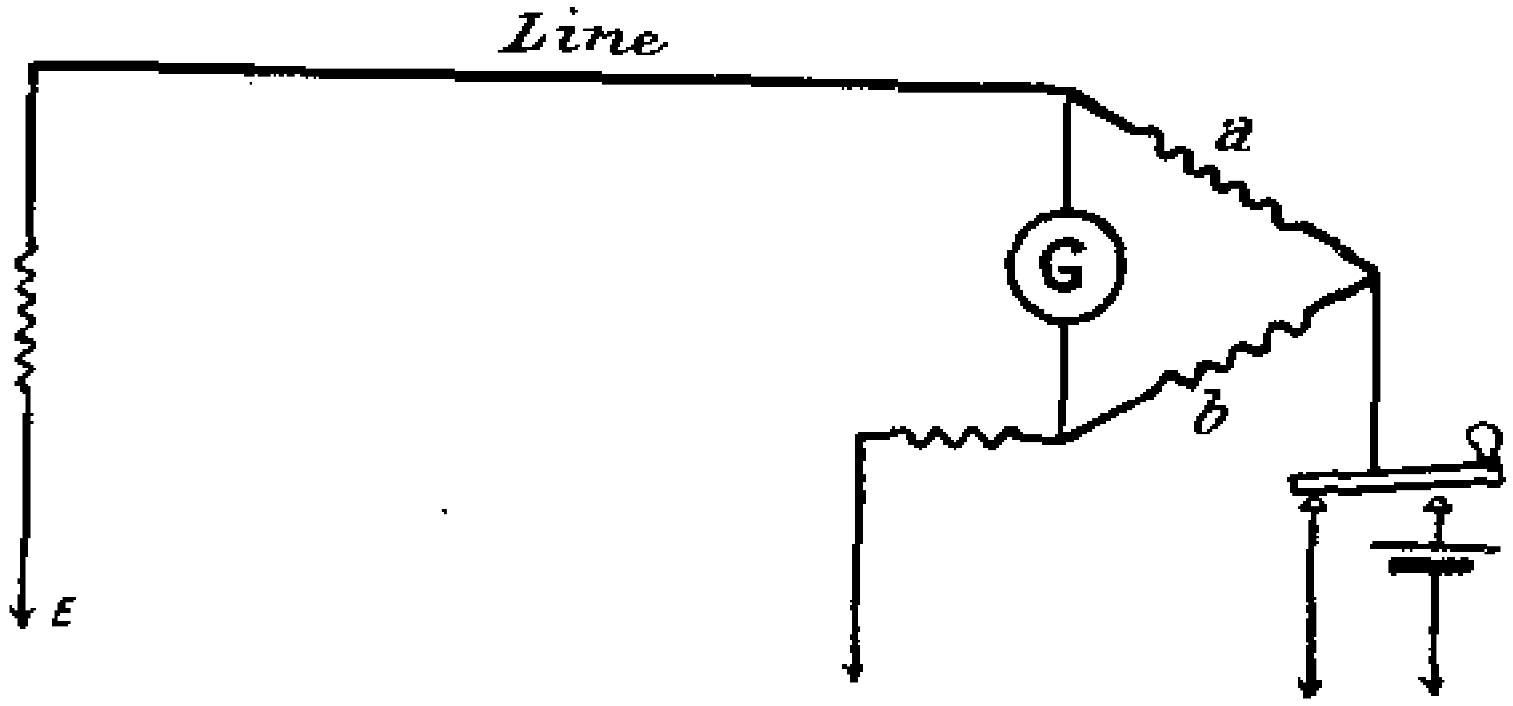


Fig. 46.—Bridge duplex principle.

In applying this principle to duplex working, the line is placed in series with an artificial resistance, the compensation circuit in series with another resistance, and the two circuits thus formed placed in parallel with each other as in the differential plan. The receiving instrument, however, instead of being in both circuits is placed between the two, as G in Fig. 46.

Generally speaking, the best arrangement is when the line (*plus* the resistance of the distant station), the compensation circuit and the two resistances *a* and *b* are all of approximately the same value. The receiving instrument, G, thus connects together the central points of the line circuit and the compensation circuit, and will be quite unaffected by the signals sent out.

Fig. 47 represents the arrangements at the two stations. To simplify matters a condenser is placed in series with the receiving instrument in the bridge, so that G is worked by impulses, and not by steady currents. As the resistance at X encountered by Y's battery is obviously that of the arm *a'*, the resistance of the line *plus* this will be something greater than that of *a*—that is, the receiving instruments do not bridge the centre points of the line and compensation circuits. The resistance of *a* and *b* is assumed to be 3,000 ohms, and the line 1,000; that in the compensation circuits will, therefore, be 4,000. The battery, of negligible resistance, is 70 volts. Now, consider the effect at the two offices of the depression of Y key, Fig. 48. The negative pole of the battery being to earth, the positive pole, directly connected to the apex of the bridge, is at + 70 volts. The apex of X bridge is to earth, so that this point is also zero. There is a fall of potential along the line circuit, and a similar fall along Y compensation circuit. At the point *f*, having fallen $\frac{3}{7}$ of 70 = 30, the potential is 70 – 30 = 40 volts, and similarly at *g*. The home receiving instrument is thus unaffected. The fall along the line is another $\frac{1}{7}$ of 70 = 10, bringing the point *k* to 40 – 10 = 30 volts. Through *a'* to earth a further fall of $\frac{3}{7}$ of 70 occurs, bringing that point to 30 – 30 = 0, or zero. No current is passing in X compensation circuit, and the point

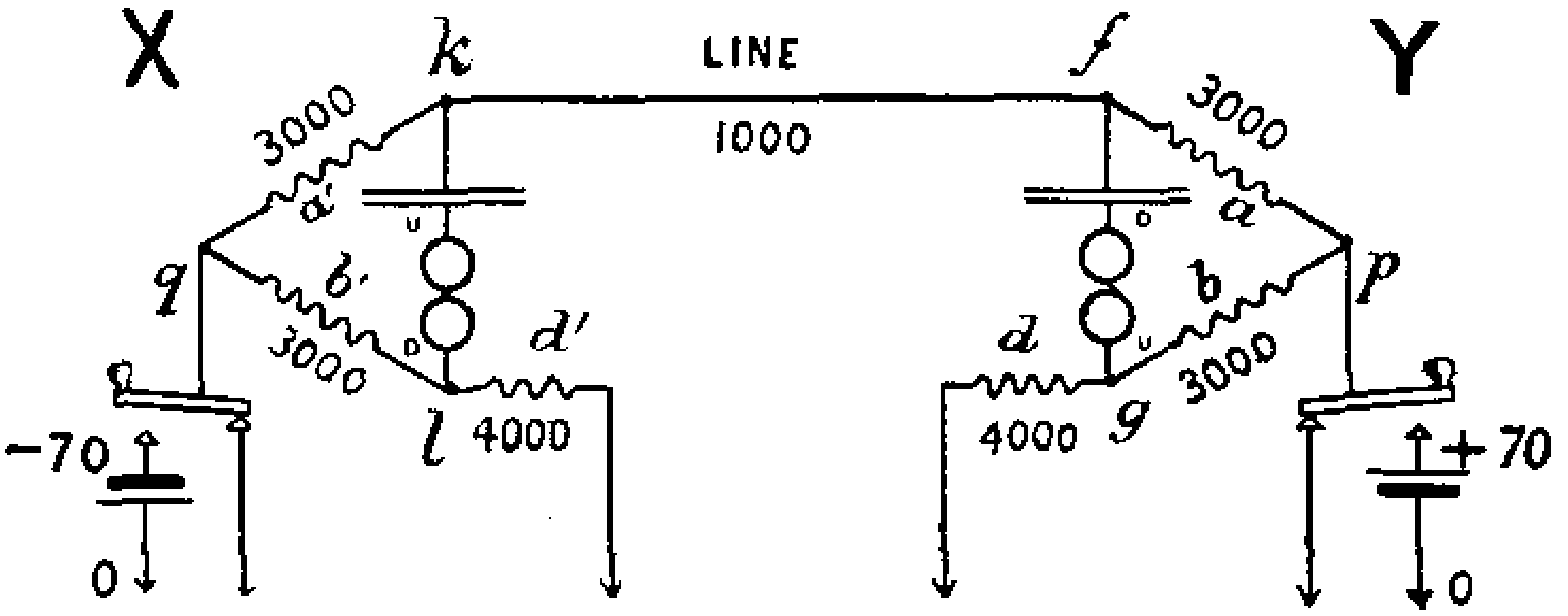


Fig. 47.

l is zero. As *k* is + 30 and *l* zero, an impulse will pass through the receiving instrument in a marking direction.

Now, consider the effect of the introduction of X battery, Fig. 49. Its positive pole is to earth; therefore, this is at zero, and the negative pole at − 70 volts. The potential, therefore, instead of falling from + 70 to zero, has to fall to 70 *below* zero; the total E.M.F. is thus 140 volts—that is, commencing at *p* where it is at its maximum, there is a fall through *a* of $\frac{3}{7}$ of 140 = 60 volts. The potential at *f* is, therefore, 70 − 60 = 10 volts. The potential falls to zero at the centre of the line, and then below zero to − 10 at *k*, and further to − 70 at *q*. The fall through X compensation circuit is all negative, and the potential at *l* is − 40. Thus, whilst *g* is 30 volts higher than *f*, *l* is 30 volts *lower* than *k*, and impulses pass through the two receiving instruments in the directions shown. It will be seen, therefore, that the effect of putting down X key (Y being down also) is to *lower* the potential at *f*, and thus work Y instrument. Regarding the circuit from the other end; when X alone puts down his key the points *k* and *l* are both at − 40 volts—the same potential—and *f* at − 30 thus working G. With X down,

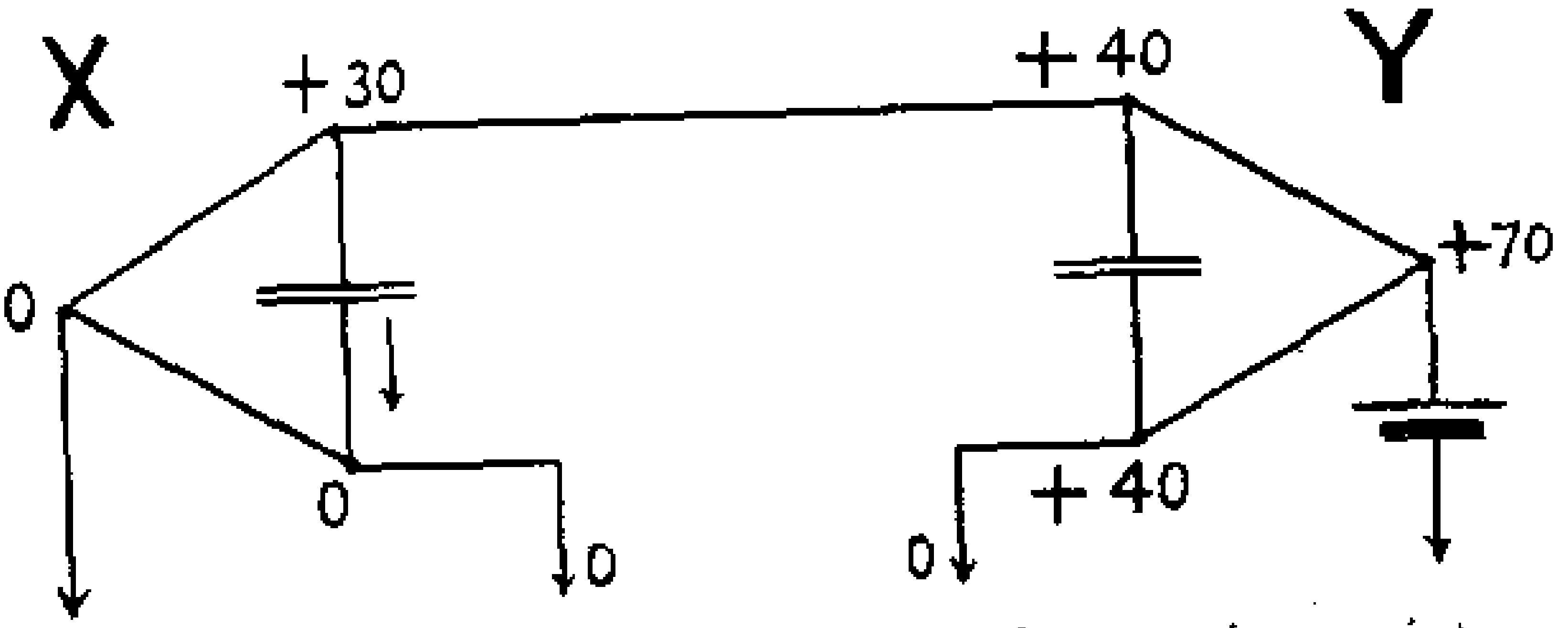


Fig. 48.—Y key depressed: potentials at various points.

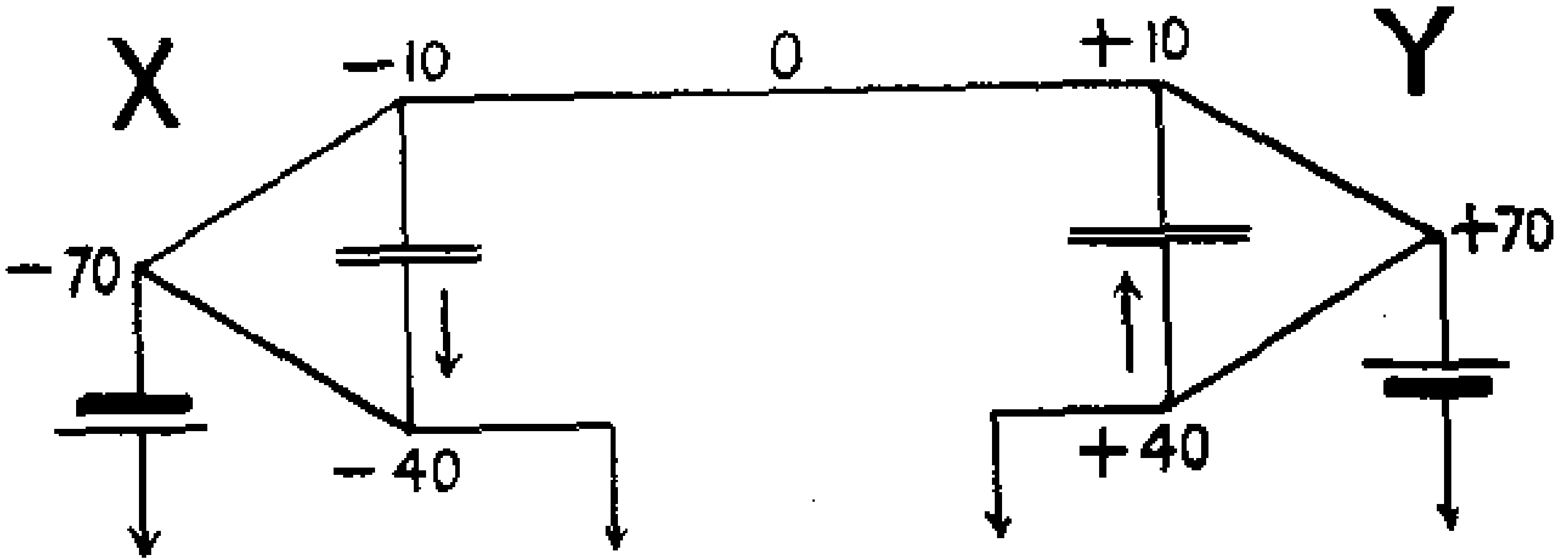


Fig. 49.—Both keys depressed: potentials at various points.

the result of depressing Y key is to *raise* the potential of point k from -40 to -10, and thus work G.

The diagrams indicate single current for the sake of simplicity, but double-current working would, of course, obtain in practice. When both keys are at rest the condition of the circuit is as shown in Fig. 49, with the exception that both batteries are reversed, and the signs of all the figures are reversed.

Fig. 50 shows X key spacing and Y marking. The points p, f, k, and q are all at the same potential—viz., $+70$—as the batteries are opposing each other in the line. The points g and l, however, are both at $+40$. Impulses, therefore, pass through the receiving instruments, marking at X and spacing at Y.

Effect of Disconnection at Key.—It will be seen that the effect of the third position of the key is the same as with the differential. Taking Fig. 48, if the point q be disconnected from the earth, the current arriving at that point has to find earth through the compensation circuit. The line current will be reduced to half its normal value, and the potential at f, k, and l will be 55, 50, and 20 volts respectively. The same difference, therefore, exists between k and l—viz., 30 volts. Thus X's reception is not affected. Y's balance will be upset, and this will result in the shortening (by an almost negligible quantity) of X's signals on Y instrument. If Y key were spacing instead of marking, X's signals would be theoretically lengthened.

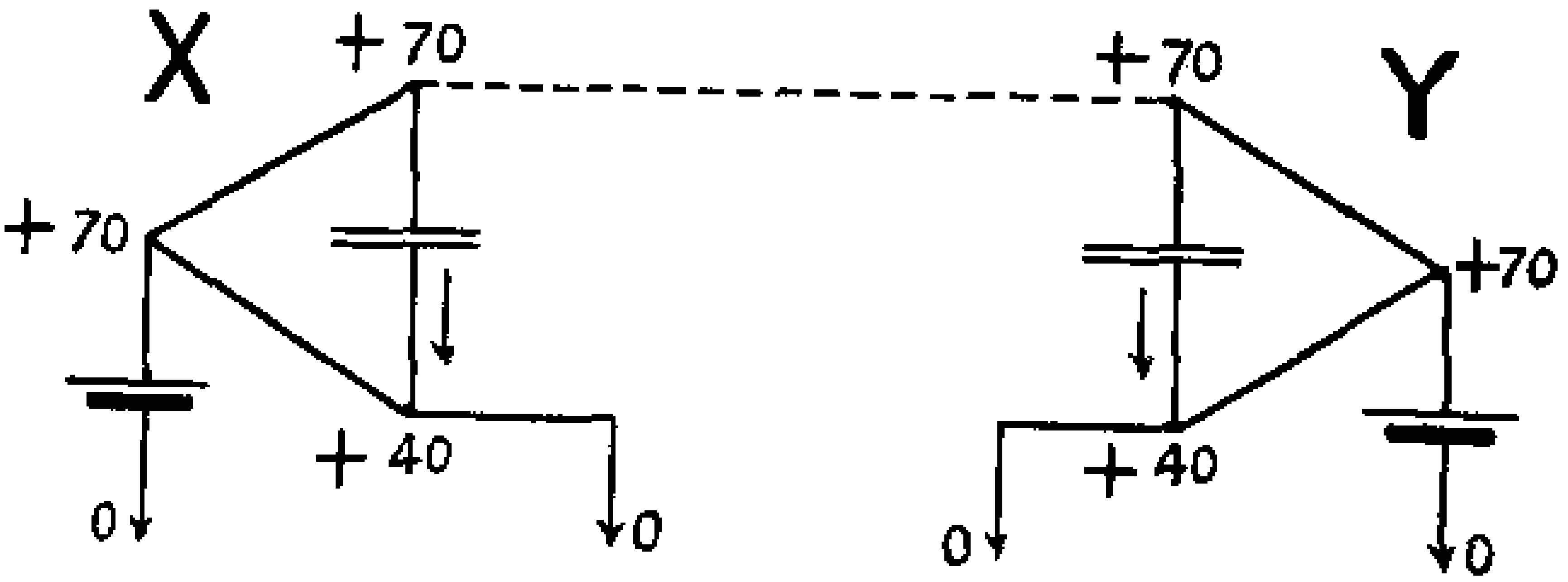


Fig. 50.--Potentials with Y key marking and X key spacing.

Further Example.—We will now consider a further example, this time without the condenser in the bridge—the latter to consist of (say) a relay and galvanometer, the total resistance being 250 ohms—as in Fig. 51—all the other values being as before.

We have to find what resistance will be required in x to balance the line *plus* the *joint resistance of the apparatus* at (say) X. For the received current on arriving at k divides into two portions, one part going direct to earth by kq, the other going through the receiving apparatus, and again dividing through lq and lx.

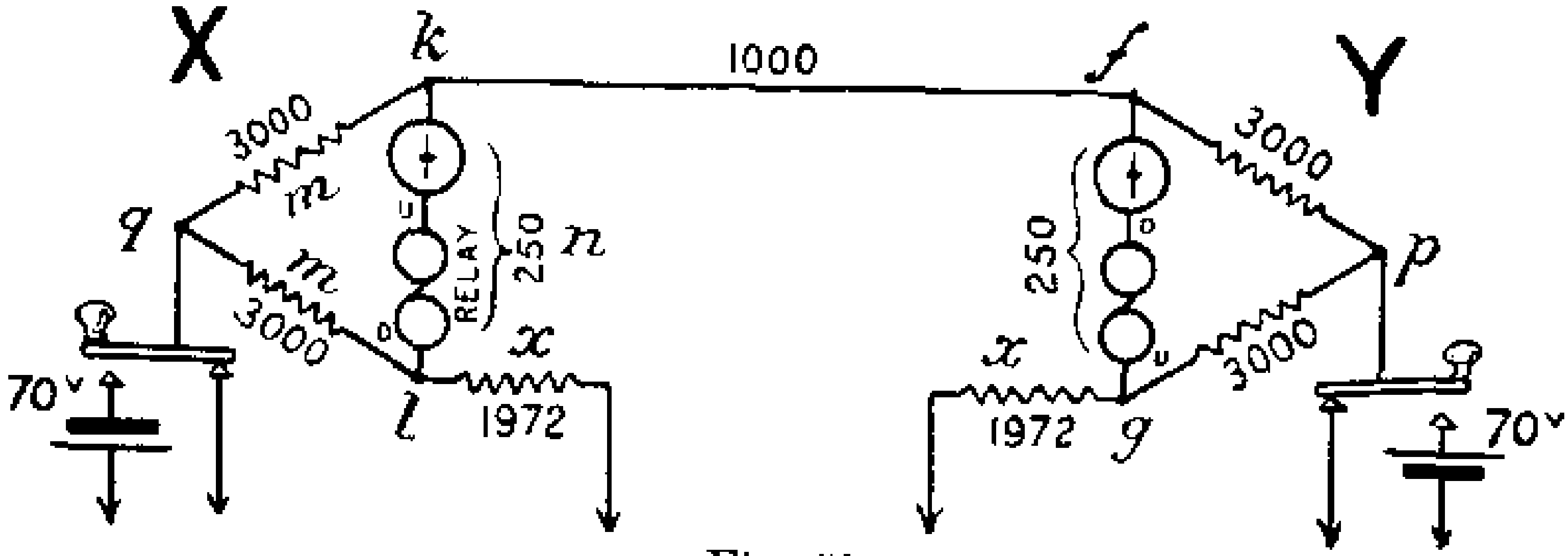


Fig. 51.

Calling the two ratios m (both being equal) and the receiving apparatus n, and the line L, the resistance (x) from the point f is

$$x = \mathrm{L} + \frac{m\left(n + \dfrac{m\,x}{m + x}\right)}{m + n + \dfrac{m\,x}{m + x}}$$

$$= \frac{\mathrm{L}}{2} \pm \sqrt{\frac{\mathrm{L}m^2 + \mathrm{L}mn + m^2 n}{2\,m + n} + \frac{\mathrm{L}^2}{4}}.$$

Inserting the above values, we get

$$x = 1{,}972 \text{ ohms}.$$

and the joint resistance from the point k = 972 ohms.

The current in the line and in the compensation circuit is, therefore, $\frac{70}{4{,}972}$ = 14 m.a.

The resistance of ql to that of x is 30 : 19, and that of kq to the receiving apparatus plus the joint resistance of ql, and x = 30 : 14. The current will divide in inverse ratio, hence 19 parts *will flow through ql, 30 through x, and the sum of these—49—* through the receiving apparatus; 23 parts will pass through qk, and the total in the line will be 72 parts. The line current is 14 m.a., hence $\frac{23}{72}$ of 14 = 4·5 m.a. will pass through qk, and $\frac{49}{72}$ of [illegible]4 = 9·5 m.a. through the receiving instrument. This is indicated by Fig. 52, where Y key is depressed. This current passing across the bridge is a "marking" one, and X receiving instrument responds.

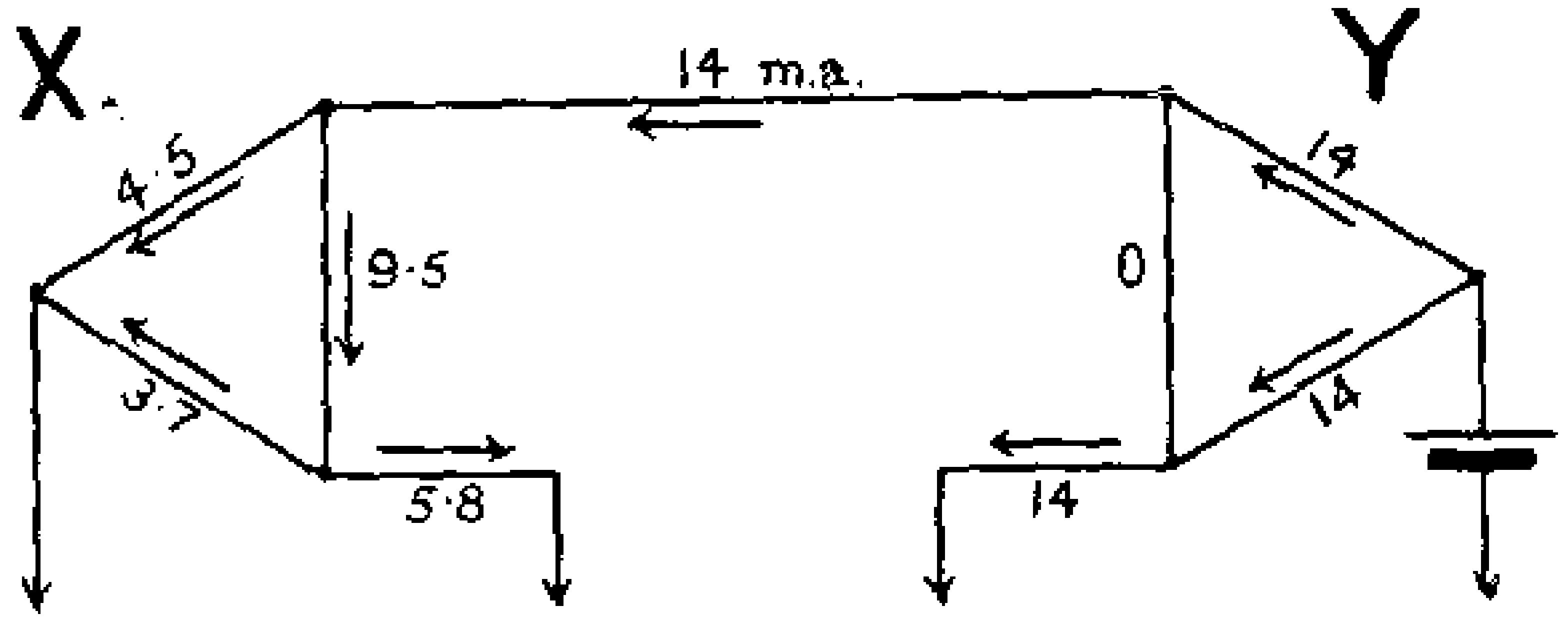


Fig. 52.—Y's key depressed.

With X key alone depressed we get the currents indicated in Fig. 53.

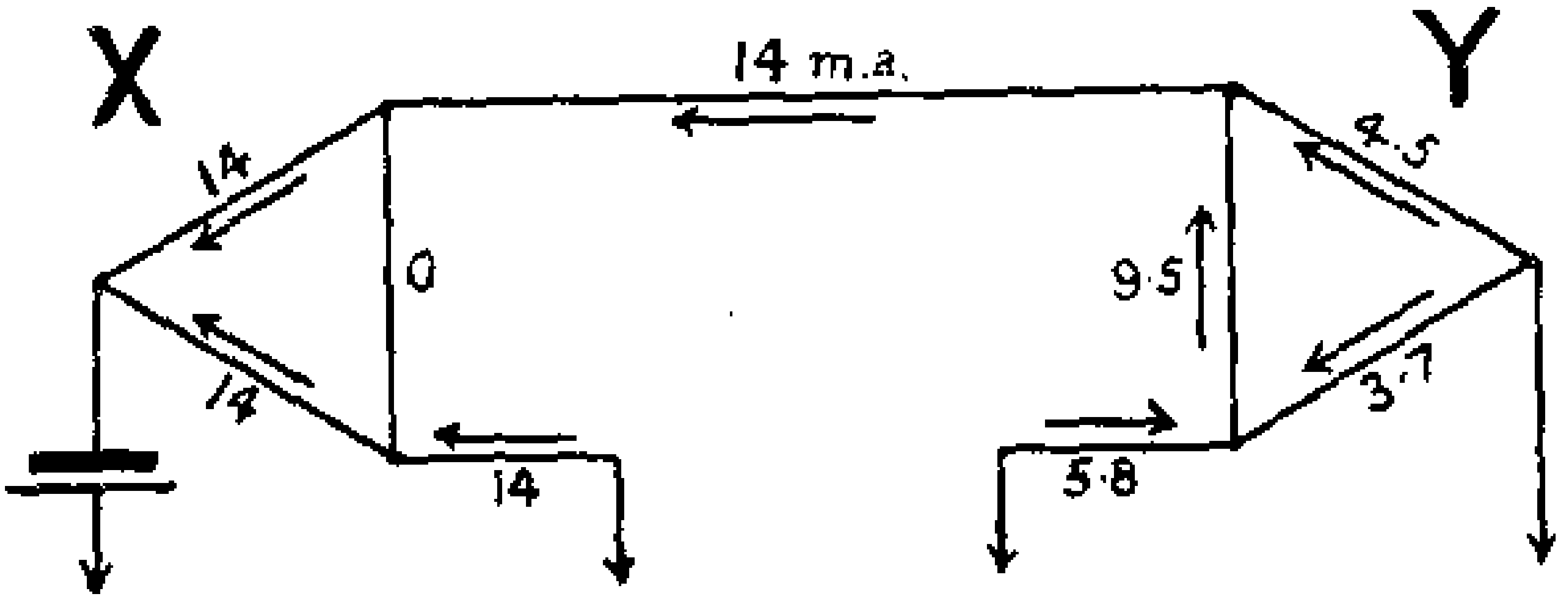


Fig. 53.—X's key depressed.

Fig. 54 shows the direction and strength of current in the different parts of the circuit when both keys are depressed.

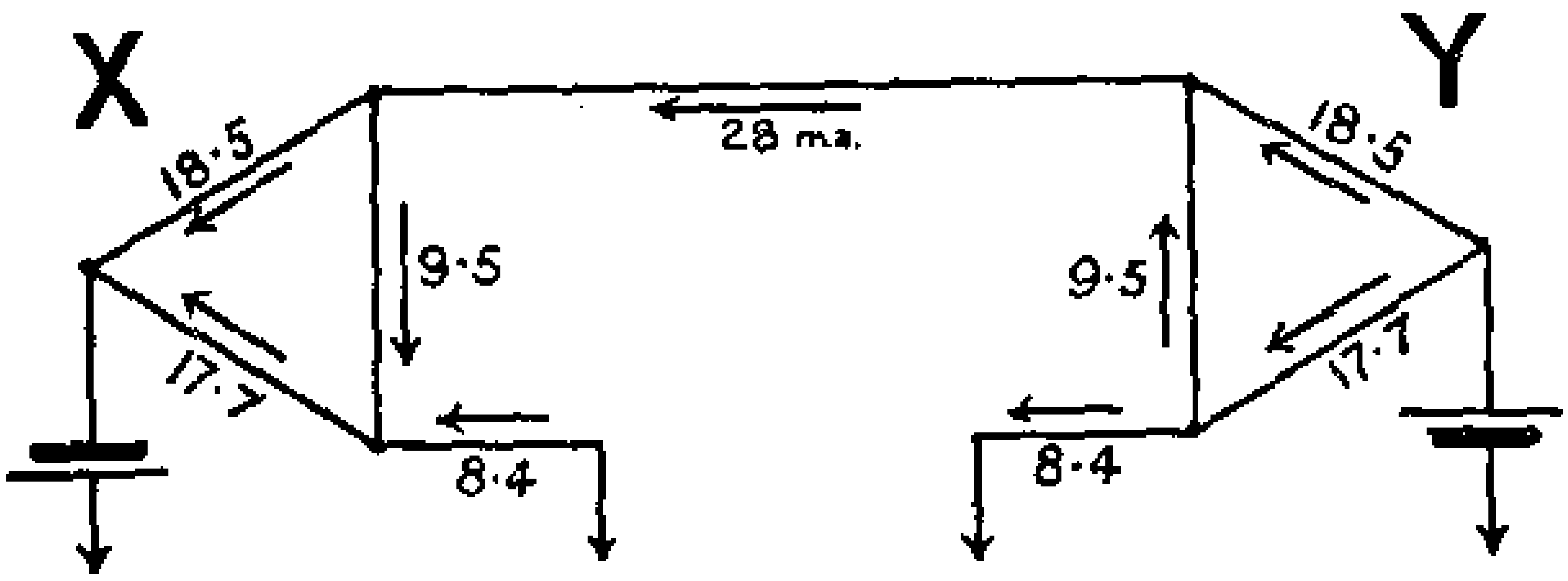


Fig. 54.—Both keys depressed.

This figure is simply Figs. 52 and 53 combined—that is, in the line is flowing the sum of the currents shown in Figs. 52 and 53

—in the compensation circuit the current is the difference between 14 and 8·5 m.a., and so on.

When both keys are spacing the currents are all of the same strength as in Fig. 54, but are all reversed in direction, and both relays "space."

When one key is up and the other down, the batteries oppose each other in the line and each station's receiving apparatus is worked by its own battery, the ratio arm *a plus* the relay, &c., being in parallel with the ratio arm *b*.

Magnetic Bridge.—In this plan the ratio arms are wound over the same iron core, and the sent-out currents pass through the windings in opposite directions. As far as the home signals, therefore, are concerned the arms are without inductance, but any portion of the received current passing this way has to encounter the full inductance of one or both coils. The effect is thus to throw the received current across the bridge, through the receiving instrument.

Comparison of Bridge and Differential Plans.—Receiving instrument in bridge is free of current when not receiving—best theoretical plan: sent-out currents thus avoid the "backing" effect of self-induction of receiving instrument. These advantages are obtained at the cost of the introduction of the high-resistance ratio arms, and, consequently, increased battery power. Further, all the received current is not available for the receiving instrument. Taking the last example. With a line of 1,000 ohms worked differentially the total resistance in the line circuit is—line itself, plus home and distant station's apparatus. Using for the latter the same figures as in the preceding example, the total = 1,000 + 250 + 250 = 1,500 ohms. To provide 10 m.a. through receiving instrument we need 1,500 × 10 m.a = 15 volts, with a total output of 20 m.a. from the battery. With the bridge, as we have seen, we require 70 volts to produce the same current through the receiving instrument, and the total output of the battery is 28 m.a.

The full diagram of a double-current sounder, duplex (bridge) or single, is given in Fig. 55, in order that it may be compared with the similar circuit of Fig. 44, worked differentially. Bridge duplex is in use on the Hughes circuits to the Continent and on the cable sides of the repeaters on the Irish wires, as we shall see. On the land lines in the United Kingdom, however, the differential method is all but exclusively employed.

In this chapter we have considered the duplex principle as applied to the hand-worked Morse or sounder circuit only, but it is equally applicable to other systems, such as the automatic and type-printing systems, to be described later. We shall deal with such applications under the different systems.

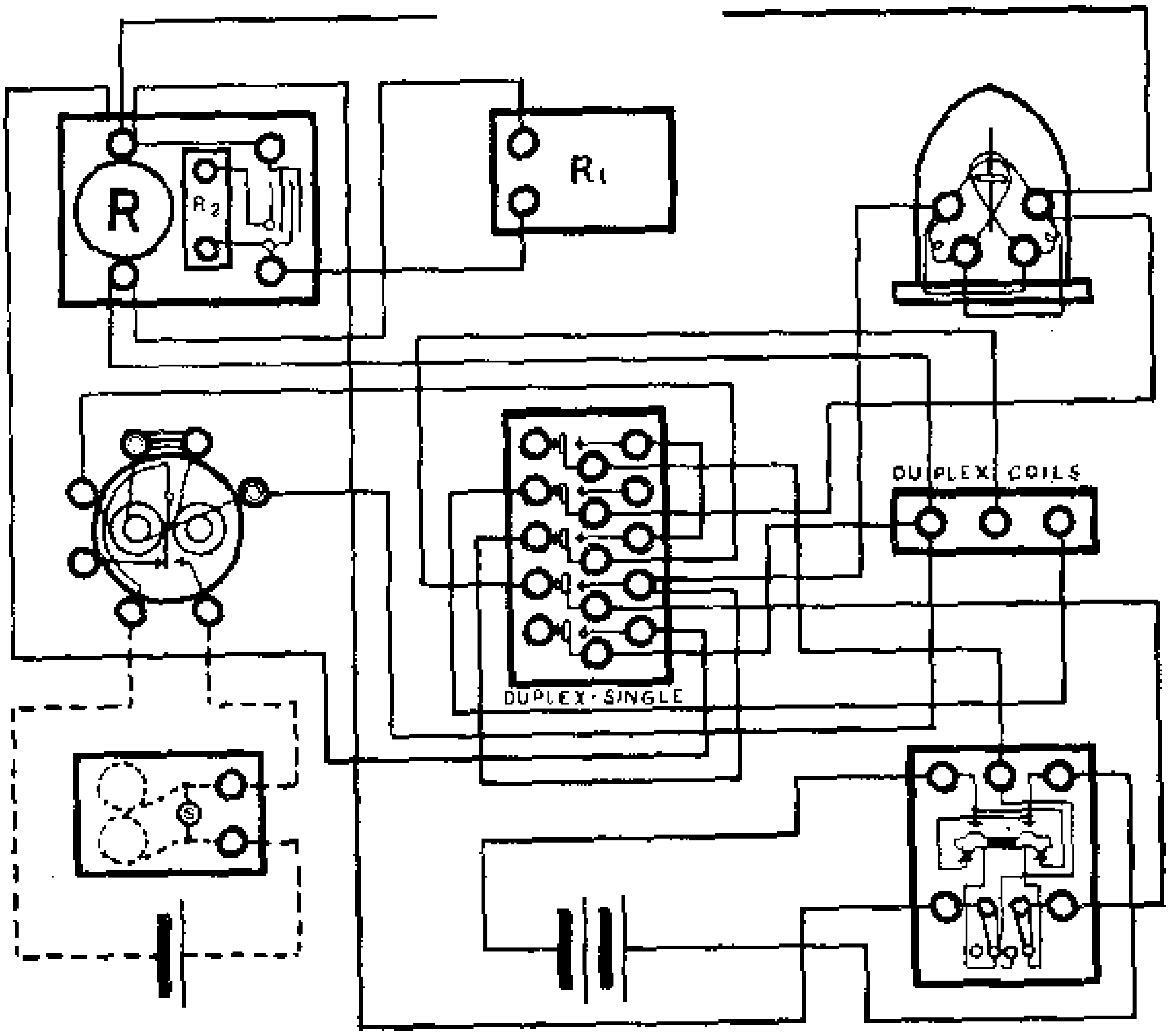


Fig. 55.—Double-current: bridge duplex or single.

CHAPTER IV.

DIPLEX AND QUADRUPLEX TELEGRAPHY.

By quadruplexing a circuit we obtain four channels or the equivalent of two duplexes, on a single line. The system may be described as a combination of the polar and Stearns duplexes of America, or in the English equivalent, double and single-current duplex combined. Electrically, it is best considered as having its root in the "diplex" system, a combination of double and single-current simplex working: this duplexed gives us quadruplex. The special difficulty of the latter—the splitting of the B side signals by the working of the A key—is inherent to the diplex system, and as it is there seen free of other complications it is the more easily understood.

Diplex.

By the duplex methods described in the previous chapter we set up two channels for communication on a single wire. By diplex we also obtain two channels, but with this difference: the two ways afforded by the former are workable only in opposite directions, station X to station Y and Y to X, whilst the two afforded by diplex are in the *same* direction, either both X to Y or both Y to X. That is, one office is fitted with two keys and the other with two receiving instruments.

In double-current working, when the key switch is turned to "send," a current is constantly flowing, whether the lever be up or down. In the first case the tongue of the receiving relay, which must necessarily be a polarized one, is kept to "spacing," and in the second case the depression of the key reverses the direction of the current and the movement of the tongue. The latter then closes the local circuit and actuates the sounder. Now, if we insert in series with the polarized relay a non-polarized instrument of equal sensitiveness, the latter will be actuated by the current in both directions, or its armature will be permanently held down. If, however, we sufficiently reduce its sensitiveness by increasing the tension of its antagonistic spring, the current, flowing in either direction, will fail to move the armature. Further, if we insert at the sending end a suitable arrangement for strengthening the current to such an extent as to overpower the spring, we shall have a means of actuating the non-polarized instrument. That is, the working of the latter will be effected by a current of suitable strength, irrespective of its direction; just as the working of the polarized relay is effected by the direction, irrespective of the strength of the current.

Fig. 56 shows diagrammatically such an arrangement as we have outlined above. A is an ordinary double-current or reversing key, B a single-current one, P a polarized relay, and N a non-polarized instrument, being a simple electro-magnet whose armature is normally held off by an adjustable spring. In order to work P we will assume that 10 m.a. are necessary, whilst N will not respond unless the current be increased to, say, three times that value, 30 m.a. The battery is in two portions, *b* and b_1, the former being sufficient to set up a current of the lesser value; whilst the whole battery $b + b_1$ furnishes the greater strength. With the apparatus in the position shown the portion *b* only is in use, the positive pole reaching A through the back stop of B. Hence a current of 10 m.a. flows, and, as this is in the "spacing" direction, it keeps the tongue of P against the spacing stop S. If A be depressed the strength of the current will be unaltered, but its direction will be changed, and P will move to "marking." In both cases N will remain unaffected. With A at rest and B depressed the "tap" wire *t* will be disconnected, and the positive pole of the whole battery brought to the reversing key. The current thus has a value of 30 m.a., and the armature of N will be attracted; being in the

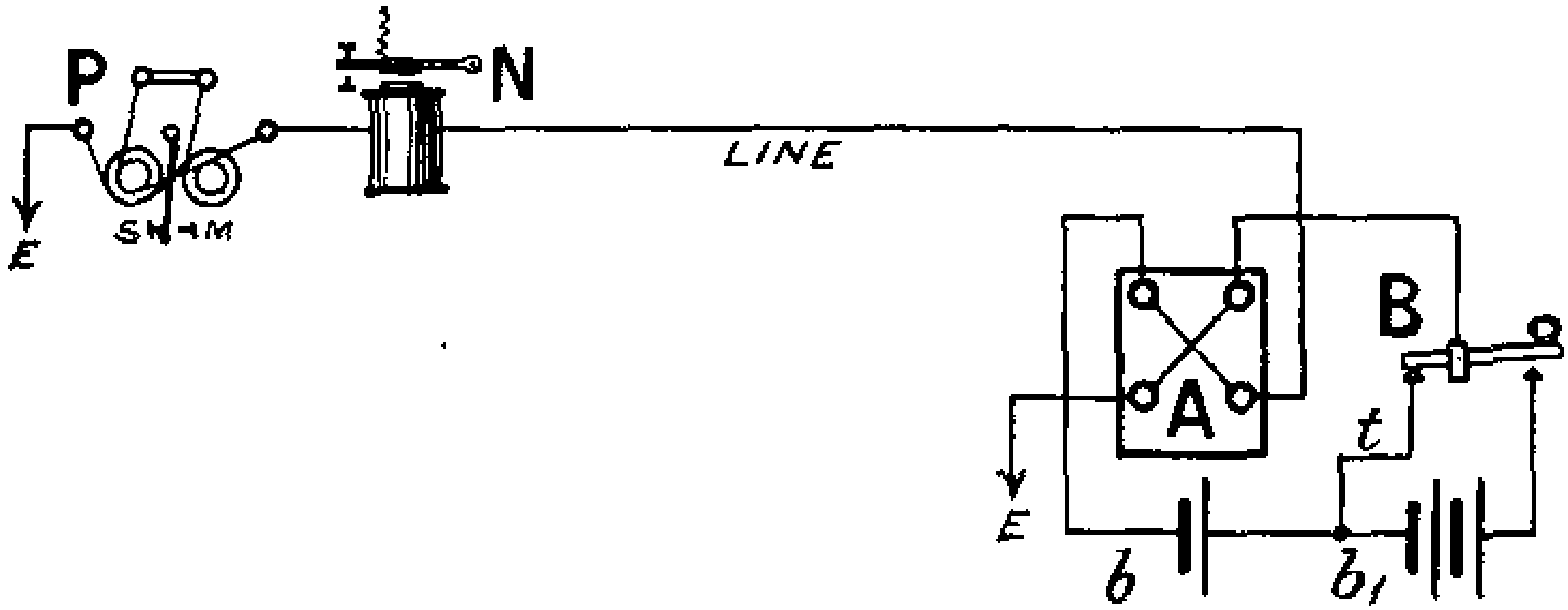


Fig. 56.

spacing direction, however, the tongue of P will be kept against S. If, now, whilst B is continuously kept down, A be depressed, the current will be reversed, but its strength unchanged. N will therefore continue to be actuated, and P will "mark." Thus a current is constantly flowing through the circuit; the depression of A reverses its direction without affecting its strength, and the depression of B increases its strength, but does not affect its direction. So long, therefore, as we keep the two values within their proper limits—that is, not allow the current from b to exceed 10 m.a., or that from $b + b_1$ to fall below 30 m.a.—the two systems will work independently of each other.

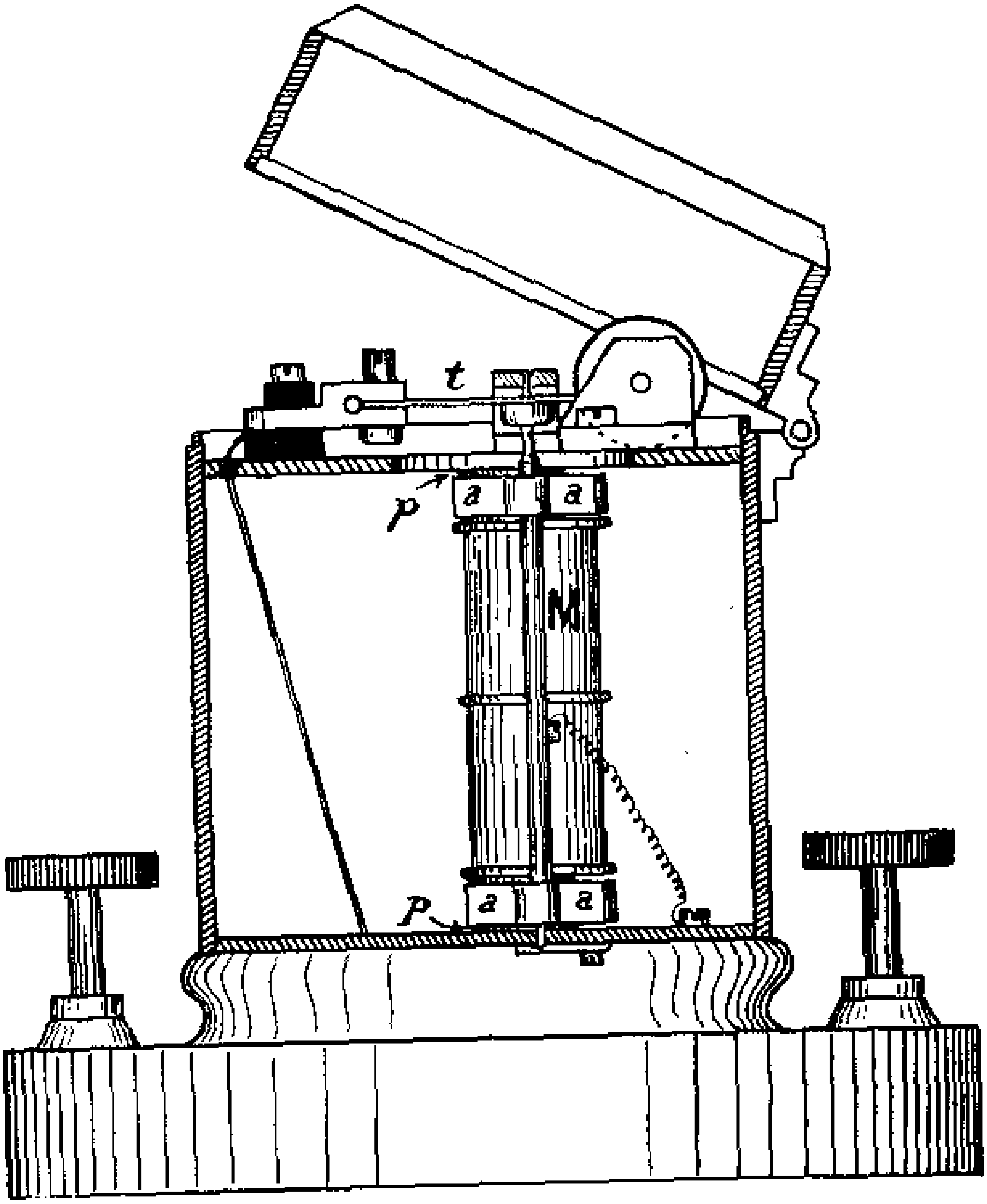


Fig. 57.—Standard non-polarized relay.

Non-polarized Relay.—We have dealt with the standard polarized instrument on p. 41. The non-polarized relay is somewhat similar in general construction, and is illustrated in Figs. 57, 58, and 59. The first is a side view. M is one of a pair of bar electro-magnets, the other being removed in order to show the two armatures *a a* and their spindle. The latter carries at its upper part the tongue *t*, which plays between the two screws *k* and *l*; the first, *k*, is provided with an insulating tip, whilst *l* is furnished with the usual platinum contact. A spiral spring attached to the rear end of the tongue keeps the latter normally against *l*, thus completing the local circuit. Each armature, of soft iron, is in two portions, separated by a layer of non-magnetic metal, as seen to the right in Fig. 58. The shape of the pole pieces *p p* of the electro-magnets, and the proximity thereto of the ends of the upper armature, can be seen in this latter figure; whilst Fig. 59 shows the cores, pole pieces, armatures, and spindle separate from the rest of the instrument. The separation of each armature into two parts, however, is not shown. The tension of the spring can be varied by means of the milled head *h* of the screw *s*. It will be apparent that the instrument has no magnetism of its own, and that a current in either direction will cause the attraction of the armatures if only of sufficient strength to overpower the spring. The relay is wound differentially to a resistance of 200 ohms each coil

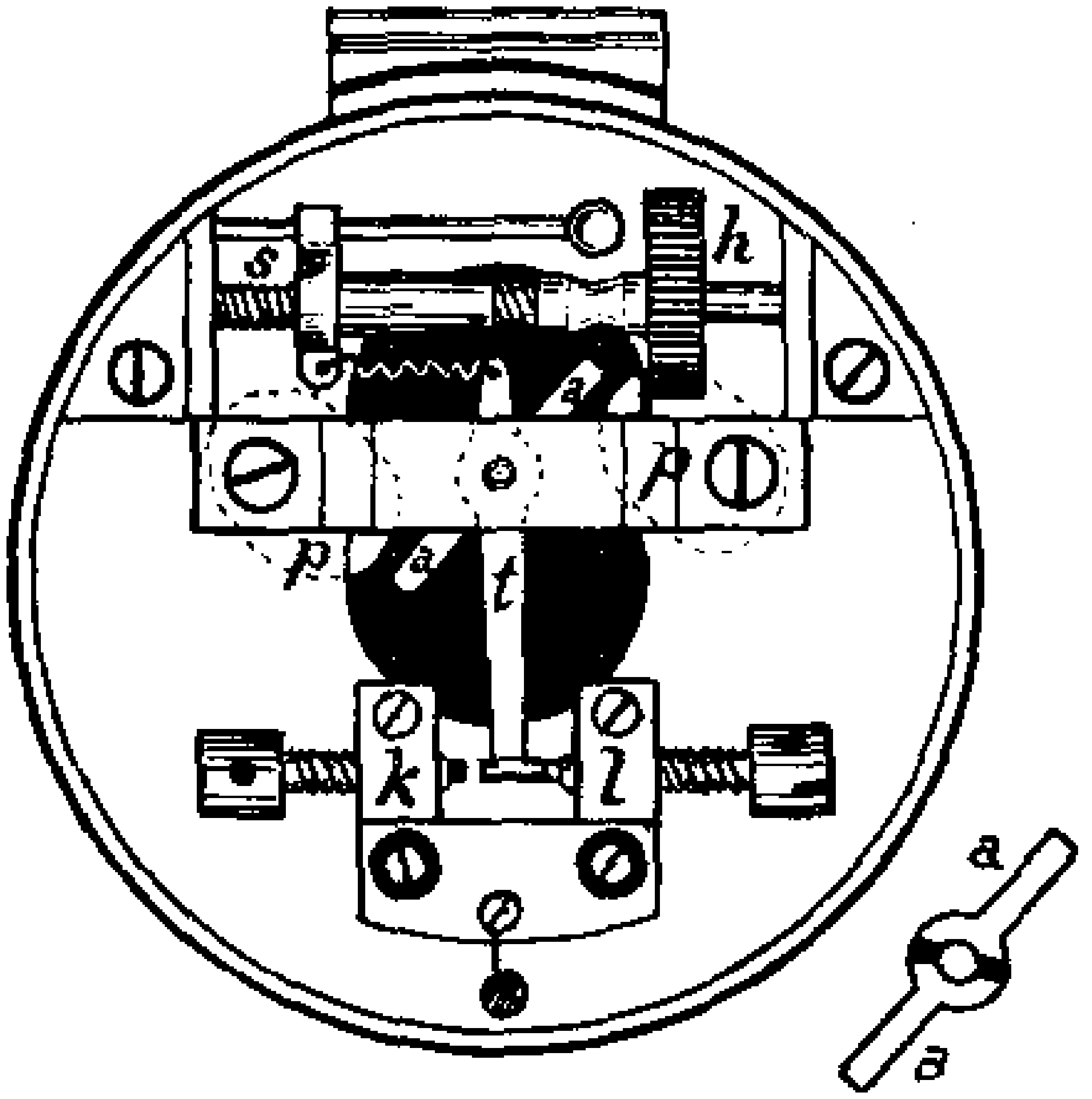


Fig. 58.—Standard non-polarized relay—plan.

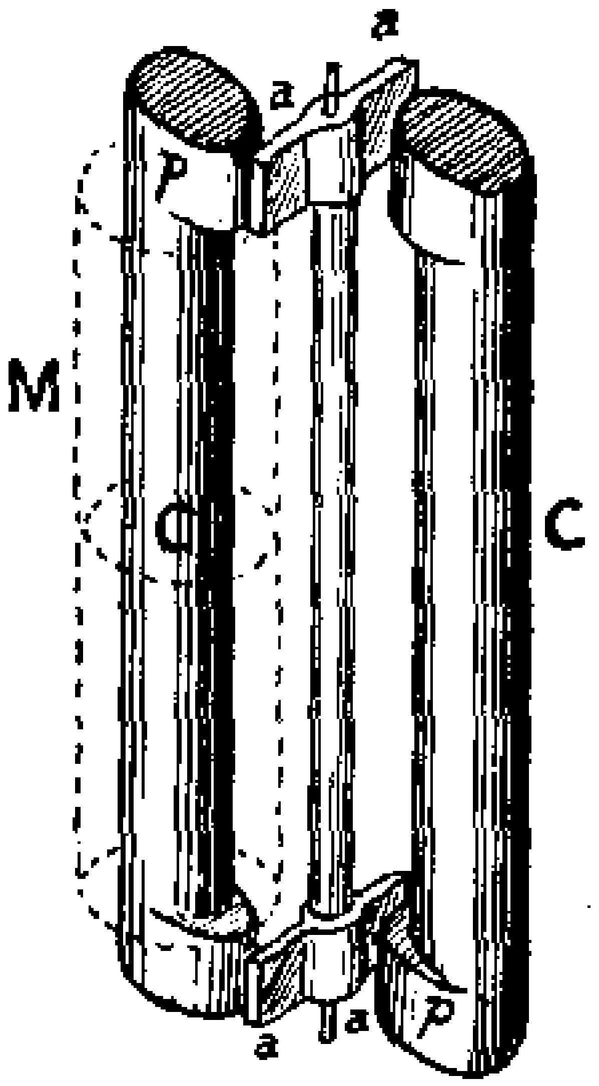


Fig. 59.—Arrangement of cores and armatures.

Short-circuiting at Keys.—Reverting to Fig. 56, it will easily be seen that in its journey from one stop to the other the increment key B—so-called because its depression increases the current—causes a momentary disconnection. Whilst this lasts, the battery, both b and b_1, is completely cut off from both keys, and the signals from the reversing key A will be split or broken. A key of the double-current pattern, with adjustable contacts, is, therefore, employed, and the contacts arranged to short-circuit the battery, which, in this case, is the portion b_1. This would result in a large current across the contacts and sparking on separation, but a "spark coil" of 100 ohms is placed in the positive lead, and the sparking thus minimised or prevented. The duration of the short circuit is, of course, made as brief as possible. By arranging matters thus we prevent the disconnection, and thereby the splitting-up of A signals, which now pass uninterrupted by the working of key B.

But a similar disconnection occurs in the middle of the journey of key A, and likewise, whilst it lasts, all current is cut off from both keys. Relay P is not affected, because its tongue is about to cross to the other stop. It is, indeed, left to its "bias" in this interval. Key B, however, may be in the middle of a signal, and the prolonged cutting-off of the current from relay N will split the signal. This is the great difficulty in diplex and quadruplex working—the breaking up of B's marks by the working of the A key. We have seen how a similar interruption of A's signals by the B key is avoided by the short-circuiting device. The contacts of A, also, are arranged to short circuit. This, however, of itself, effects no improvement. That is to say, if the short circuiting is of equal duration to the disconnection, matters will be precisely as before, since the battery is cut off in both cases, and for the same interval. The period of the cutting-off of the battery is carefully reduced to a minimum, thus tending to prevent the release of the armature of N between the reversals of the current and to keep it continuously attracted.

When the whole of the battery, $b + b_1$, is in use it will be seen that the resistance is more than proportionately larger than when the portion b only is in use, because in the former case the spark coil is added. A second coil, approximately equal to the resistance of the portion b_1 plus the spark coil, is, therefore, placed in the tap wire. Hence when either a part or the whole battery is in use its resistance is the same. This coil in the tap wire also serves to prevent sparking at the short circuit of the A key.

In consequence of the introduction of these two coils the "short-circuit" is not absolute, either with A or B. With the latter, the portion b_1 is short-circuited through the tap resistance plus the spark coil. The battery b_1, therefore, during this interval sends a small portion of its current through the main circuit. The short-circuit of A takes place through the tap resistance when B is at rest, and through the spark coil only when B is depressed; in this latter case the whole battery being involved. The effect of the middle position of A, in both cases, is to cut off the battery entirely from the system.

Local Circuit of B Relay.—As we have already seen, the object of causing the A key to short-circuit is to minimise the time of the cutting-off of the battery at the reversal of the current, and to prevent the release of the armature of the B relay, or to reduce such release to the shortest possible time. By the arrangement of the B local circuit this momentary release is prevented from being reproduced on the sounder.

First, suppose the local circuit to be joined up in the ordinary way, so that it is normally incomplete, the insulated stop being at *l*, on the right (Fig. 58). When the B key is depressed the armature of the B relay moves over to stop *k*, and the sounder is actuated. If key A be depressed whilst B is held down, and the cutting-off of the battery lasts long enough to allow the tongue to *leave k*, the act of breaking contact with *k* will split the signal on the sounder.

This arrangement, however, is reversed, the stop *k* being the insulated one, as in Fig. 58, and stop *l* being in use. The local circuit is thus normally closed, and the movement of the tongue breaks it. Clearly, the sounder cannot be placed in this circuit, or it will be "reversed." Hence an intermediate instrument, an "uprighting" or "relaying" sounder, is placed there. This is fitted with contacts, which in their turn complete a second local circuit, which includes the reading sounder.

Relaying Sounder.—Two views of this instrument are given in Fig. 60. It is practically the same, in its main features, as the ordinary reading sounder, but its armature lever is provided with contacts, and plays between two contact stops. The coils, wound to 40 ohms, are shunted by a resistance equal to themselves. The effect of this is that when the working current is cut off, the "extra current" of self-induction has a path of comparatively low resistance in which to circulate. The demagnetisation of the cores and the release of the armature are thus delayed. Further, as the armature is slow in rising at the cut-off of the current, it is necessarily (but not correspondingly) slow in moving *towards the cores on the completion of the circuit. It is this* action which furnishes a margin in the working of the local circuit, as we shall see.

Fig. 61 gives the theoretical connections of a diplex circuit. At the receiving end R is the relaying sounder. When the B key is at rest the armature of N is kept, by means of its spring, against the right-hand contact. This circuit is thus normally closed, and the armature of R is permanently attracted. When the B key is depressed, and the tongue leaves the right- for the left-hand contact, the armature of R is released, and completes the circuit of S, which is then actuated. Now, whilst this state of things continues, let us suppose the A key to be put down. If the interval of cut-off is prolonged, it is quite conceivable that the tongue of N may "chatter" on the insulated left-hand stop, or be partially released therefrom; but, so long as it does not reach the right-hand stop, the coils of R are unaffected, and its armature remains unattracted. The signal on the reading sounder is, therefore, free from mutilation.

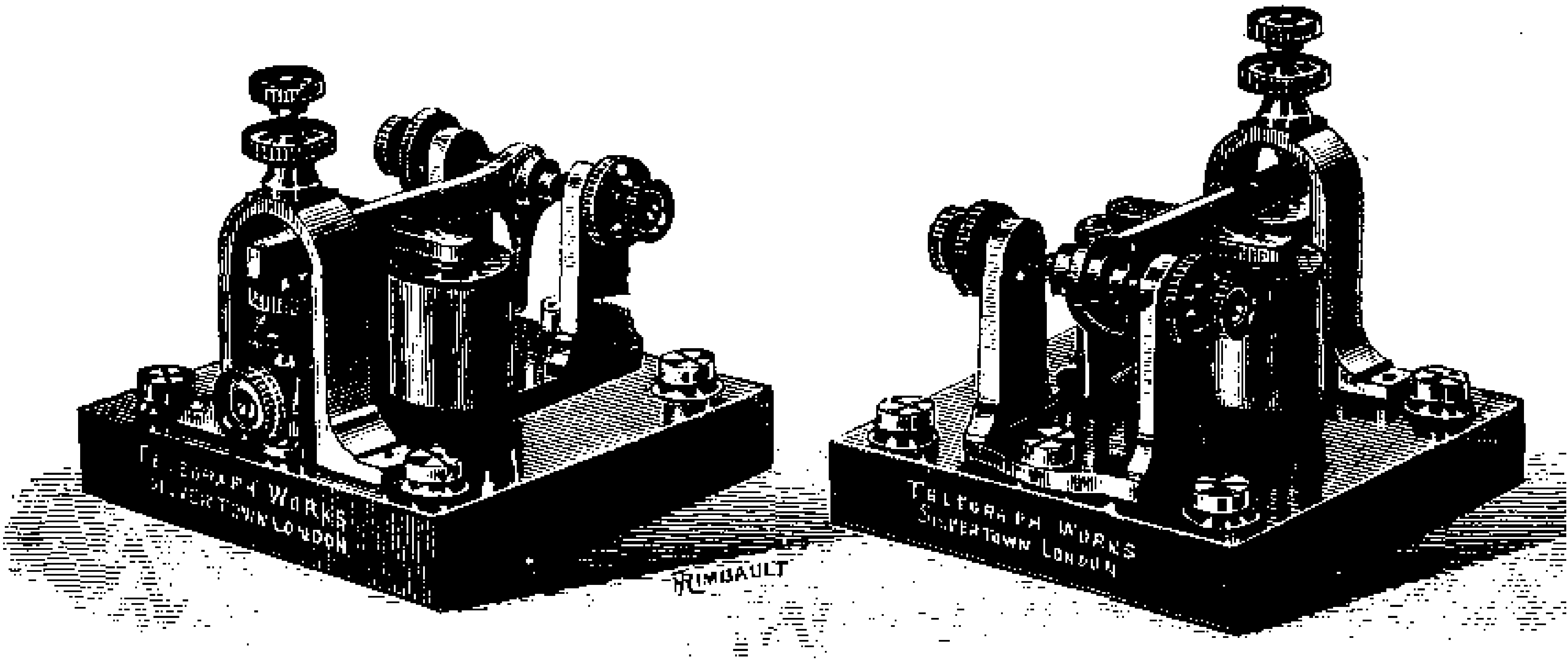

TELEGRAPH WORKS SILVERTOWN LONDON
TELEGRAPH WORKS SILVERTOWN LONDON
RIMBAULT

Fig. 60.—Relaying sounder.

Again, if the cut-off of the battery at the A key should be sufficiently prolonged to allow the tongue of N to reach the right-hand stop, and send a momentary "flick" of current through the coils of the relaying sounder, the sluggishness of the latter's movements may prevent the armature from responding.

Decrement Plan.—The diplex system as detailed above is worked on the "increment" plan, so-called because the depression of the B key increases the strength of the current. The reverse plan, the "decrement" is sometimes employed. By the reversal of the two battery wires on the B key the full battery, $b + b_1$, is normally in use, and the depression of this key cuts off the portion b_1, hence the B key is termed the decrement key. This leads to simplification in the local circuit of N. The tongue is normally held over by the full current against the insulated left-hand stop. When the B key is depressed and the armature of N thus released, the local circuit is completed. The ordinary reading sounder is, therefore, placed here, and the relaying instrument dispensed with. Since the sounder is actuated by the cutting-off of the current from the relay, the prolonged break of A key clearly can have no effect on the signal. Its effect will now be felt when the B key is at rest and will give momentary false signals, if of sufficient duration. There is the same margin of safety at the contacts of the relay, for if the tongue does not reach the right-hand contact, its chattering on the other (insulated) stop will do no harm. The margin due to the sluggishness of the relaying sounder, however, will not now be available.

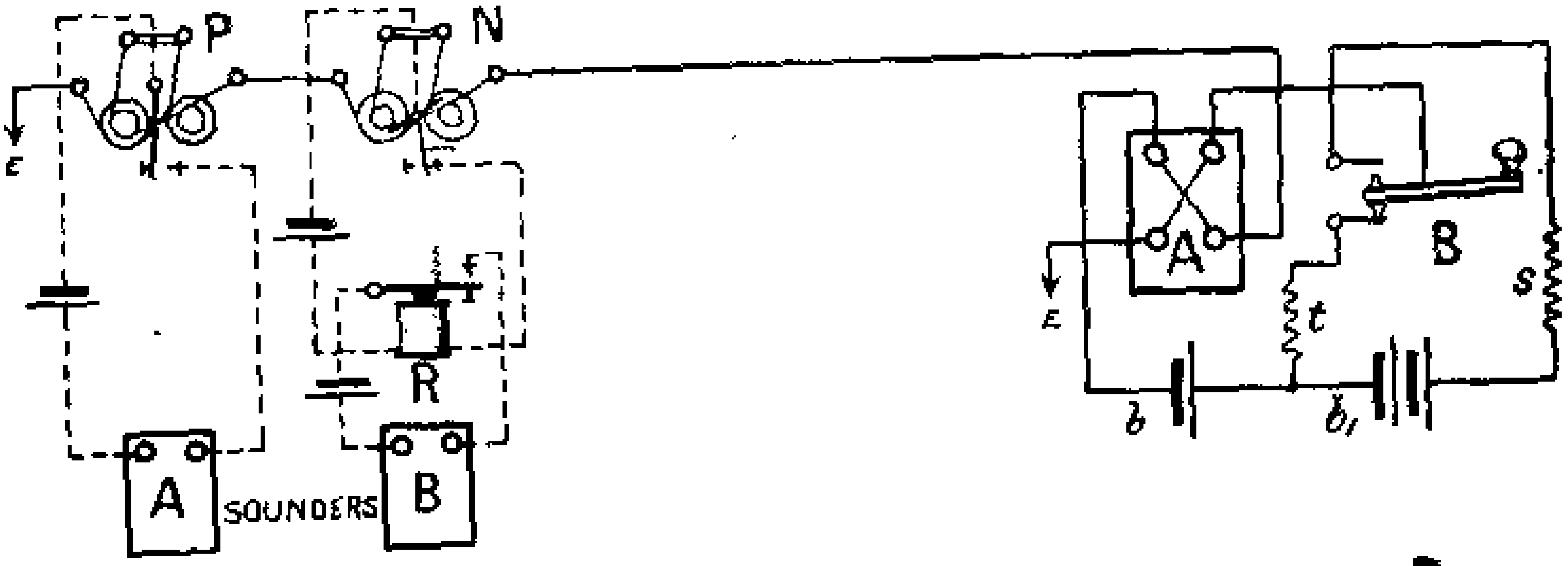


Fig. 61.—Diplex circuit (theoretical).

Diplex Diagram.—To provide two keys at one station for sending and two relays, &c., at the other for receiving would clearly be insufficient, since there would be no means of com-

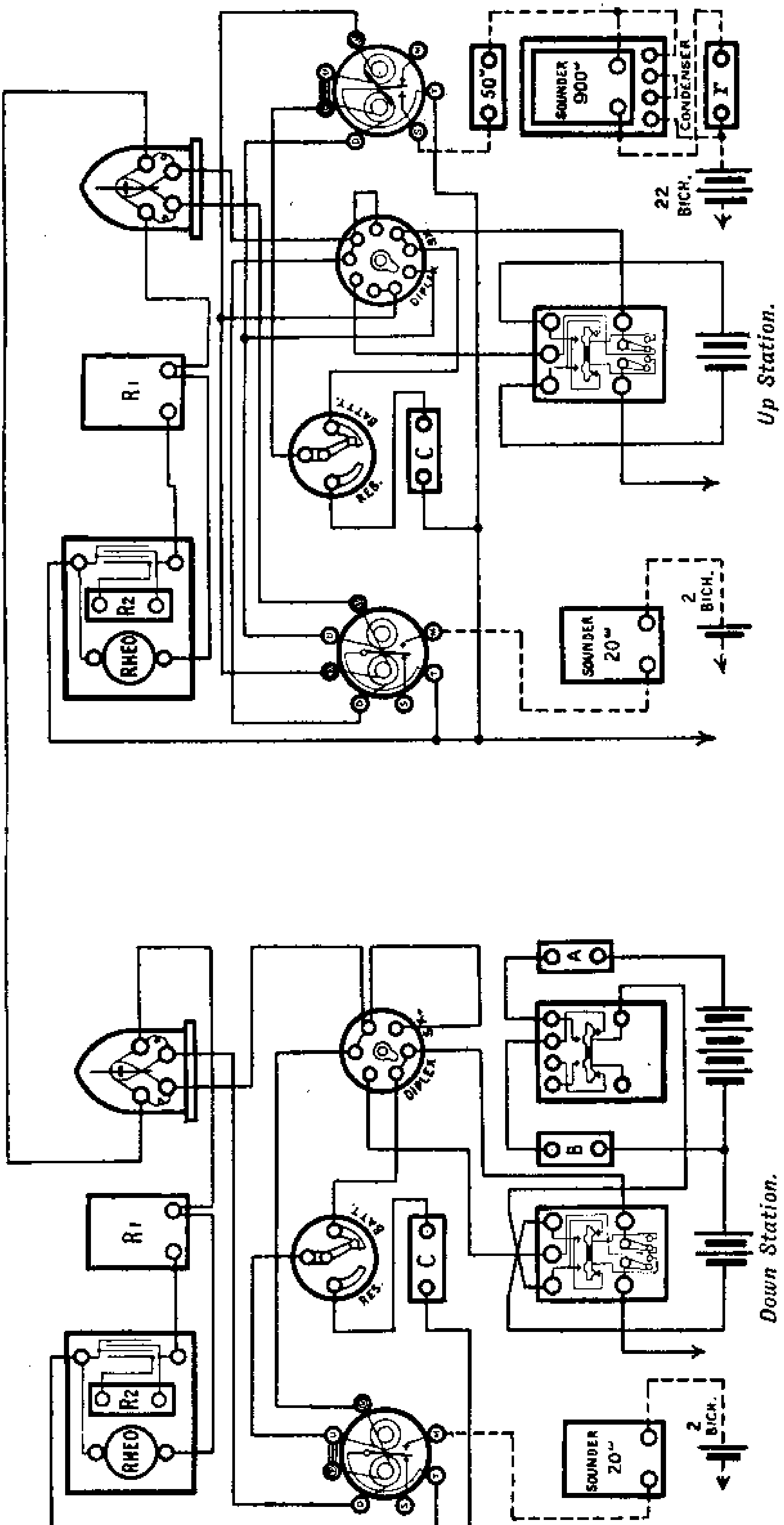


Fig. 62.—Diplex or single.

munication in the other direction, even for the sending of acknowledgments. Hence, an additional relay and sounder at the sending and an additional key at the receiving station are added to the equipment. Further, to work such a circuit "simplex" would be impracticable, because the turning of the switch on the A key to "receive" would cut off the B key as well. It is, therefore, usual to duplex the arrangement on the differential plan. We then have two channels in one direction and a single channel in the other. The circuit then becomes a "triplex" rather than a diplex, or, as more commonly understood, a modified quadruplex. This is shown in Fig. 62. Many of the details given, however, will be better understood after a consideration of quadruplex itself.

Fig. 63 illustrates the interaction of the currents due to the working of the two keys on a diplex circuit. The shaded portions above and below the central line indicate the marking

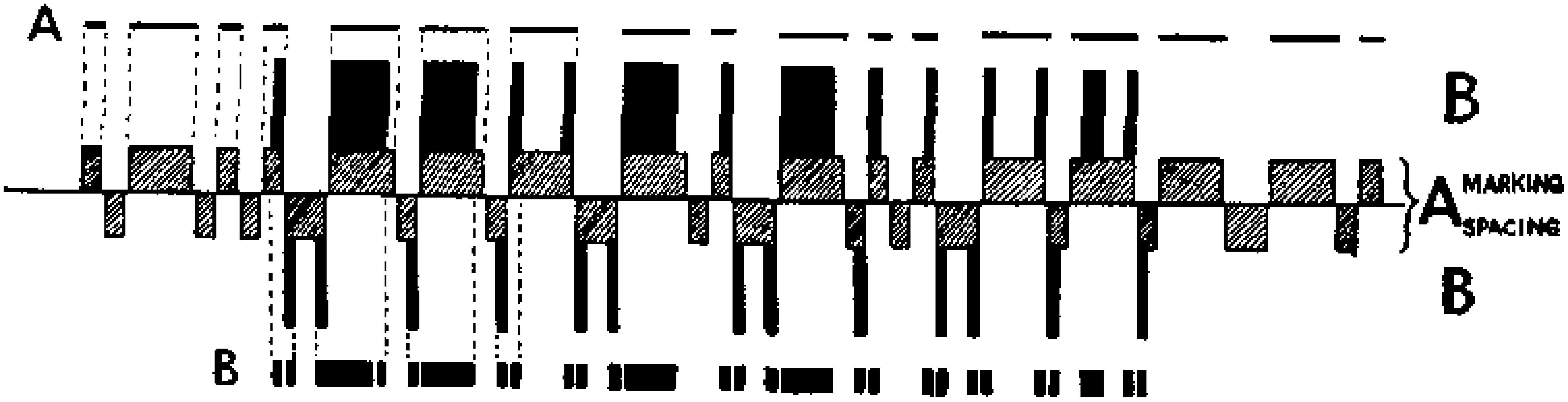


Fig. 63.—Interaction of A and B keys on a diplex circuit.

and spacing currents sent by the A key. The full black portions represent the strengthening of those currents (irrespective of their direction) by the depression of the B key. Wherever the current is reversed it results in a cutting of the B signals as shown in the lower line ("PARIS"). For successful diplex or quadruplex working, this cutting must be prevented from extending to the receiving sounder.

QUADRUPLEX.

We now come to the duplexing of the diplex system just described. The differential method, treated of in Chapter III., is practically always employed. For simplicity and for uniformity of treatment we shall follow the diagrammatic method used in Figs. 42 and 43 and assume that the up and down station connections are the same, except at the line and earth terminals.

Further, with the positive pole of the battery towards the galvanometer, a marking current is indicated. Where one cell is shown it represents the battery on the A side only, whilst the current from it is assumed to be of "strength 1" and is indicated by a single arrow in the line and a single arrow in the compensation circuit. The direction is obvious from this. Three cells indicate that the whole battery is in use, owing to the depression of the B key. This, we assume, trebles the value of the current *in all branches of the circuit and is indicated by three arrows.*

There are four possible combinations of the keys at each station, viz.:—

A key at rest and B key at rest.
A ,, depressed ,, B ,, ,,
A ,, at rest ,, B ,, depressed.
A ,, depressed ,, B ,, ,,

And further, with the apparatus at one station in each of these positions, there is the same number of possible positions at the other station—that is, there are sixteen different combinations for the whole circuit. For clearness we will enumerate them:—

Position.	STATION X.	STATION Y.
I.	A at rest, B at rest.	A at rest, B at rest.
II.	A ,, B ,,	A depressed, B ,,
III.	A ,, B ,,	A at rest, B depressed.
IV.	A ,, B ,,	A depressed, B ,,
V.	A depressed, B at rest.	A at rest, B at rest.
VI.	A ,, B ,,	A depressed, B ,,
VII.	A ,, B ,,	A at rest, B depressed.
VIII.	A ,, B ,,	A depressed, B ,,
IX.	A at rest, B depressed.	A at rest, B at rest.
X.	A ,, B ,,	A depressed, B ,,
XI.	A ,, B ,,	A at rest, B depressed.
XII.	A ,, B ,,	A depressed, B ,,
XIII.	A depressed, B depressed.	A at rest, B at rest.
XIV.	A ,, B ,,	A depressed, B ,,
XV.	A ,, B ,,	A at rest, B depressed.
XVI.	A ,, B ,,	A depressed, B ,,

We will now consider these, not in this order, but in the order of their electrical complexity. The sixteen possible positions *will be found to fall into three natural groups*—(1) *with both* B keys at rest, (2) with both B keys depressed, and (3) a mixture of the two. Looked at from the point of view of station X, position IV. is the same as position XIII. regarded from station Y; similarly with II. and V., XII. and XV., III. and IX., VII. and X., VIII. and XIV. This reduces the number of combinations from sixteen to ten.

1. B Keys at Rest.—Under these conditions the circuit is simply worked duplex, and we have three combinations—both A keys at rest (position I.), both depressed (VI.), one at rest and the other depressed (II. and V.). In the first two cases the batteries at the two stations are augmenting each other in the line circuit, so that in the coils of the relays the line current preponderates to the extent of our strength "1." This is sufficient to actuate the A relays, but not the B's. In the third case the batteries are opposing each other, so that no current flows in the line coils. The relays are therefore actuated by the compensation currents, which are also of strength 1. The B relays throughout are unaffected.

2. B Keys Depressed.—These, again, are purely duplex conditions worked by the full battery power. There are three combinations—both A keys at rest (XI.), both depressed (XVI.), one at rest and the other depressed (XII. and XV.).

With both A keys at rest, and both depressed, we have the batteries at both stations combining their effects in the line coils, so that the strength in the latter to that in the compensation coils is as 6 : 3 = a preponderance of 3 which actuates the B relays. With one A key up and the other down the batteries oppose each other, and the compensation currents actuate the relays. The strength of these is 3; hence both B relays are affected.

3. One B Key Depressed, the other at Rest.—Figs. 64 to 67 indicate matters when the full battery is in use at one station and the small portion at the other.

In Figs. 64 and 65, the two A keys occupying similar positions, the two unequal batteries are adding to each other's effects in the line circuit and bringing the current there to our conventional strength 4. At station X the difference between line and compensation currents is, therefore, 4 − 3 = 1. This strength is insufficient to work the B relay there. At station Y the difference is 4 − 1 = 3, which actuates Y's B relay. In both diagrams it will be seen that the *directions* of the currents are such as to cause the A relays to follow the positions of

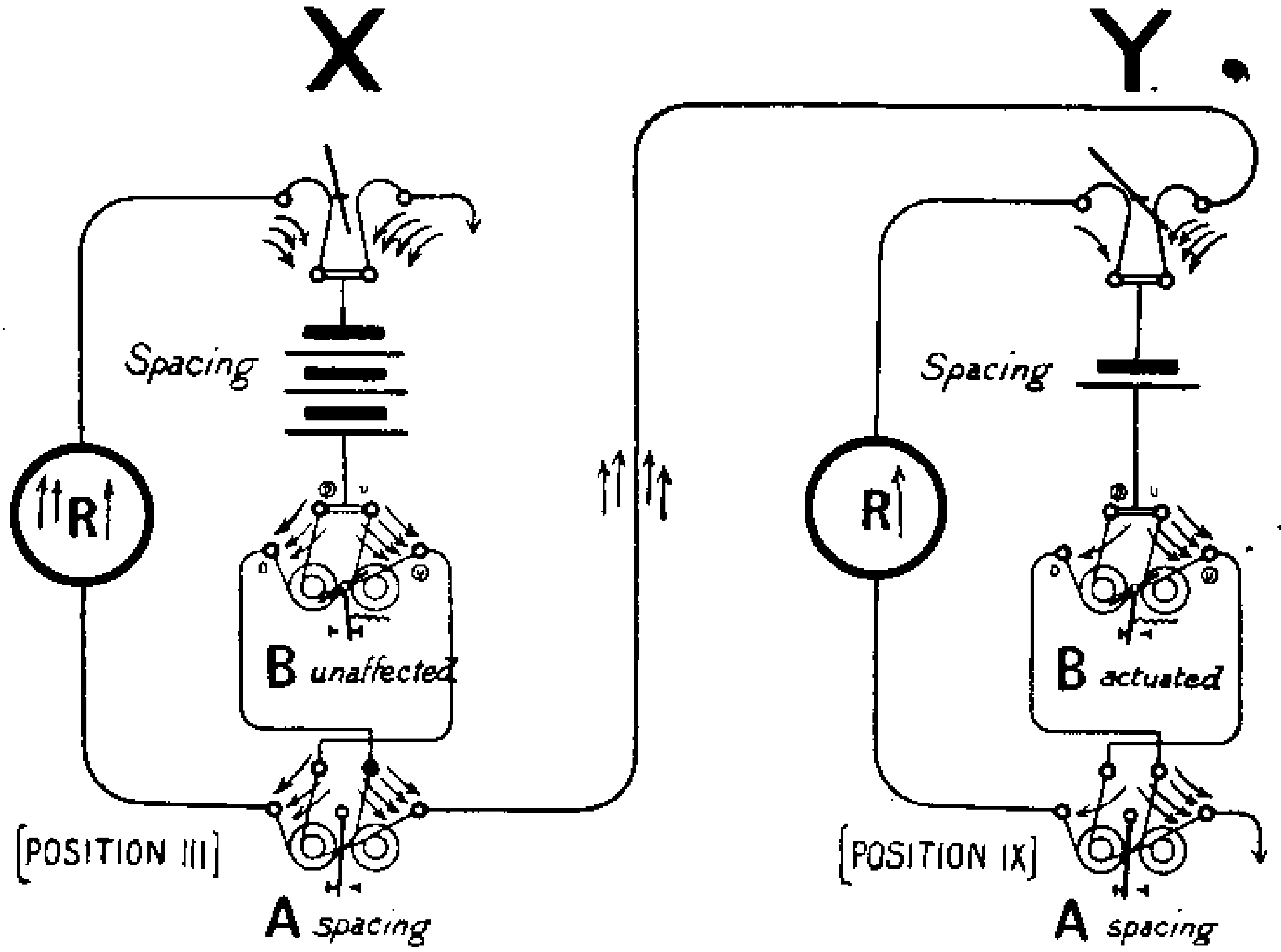
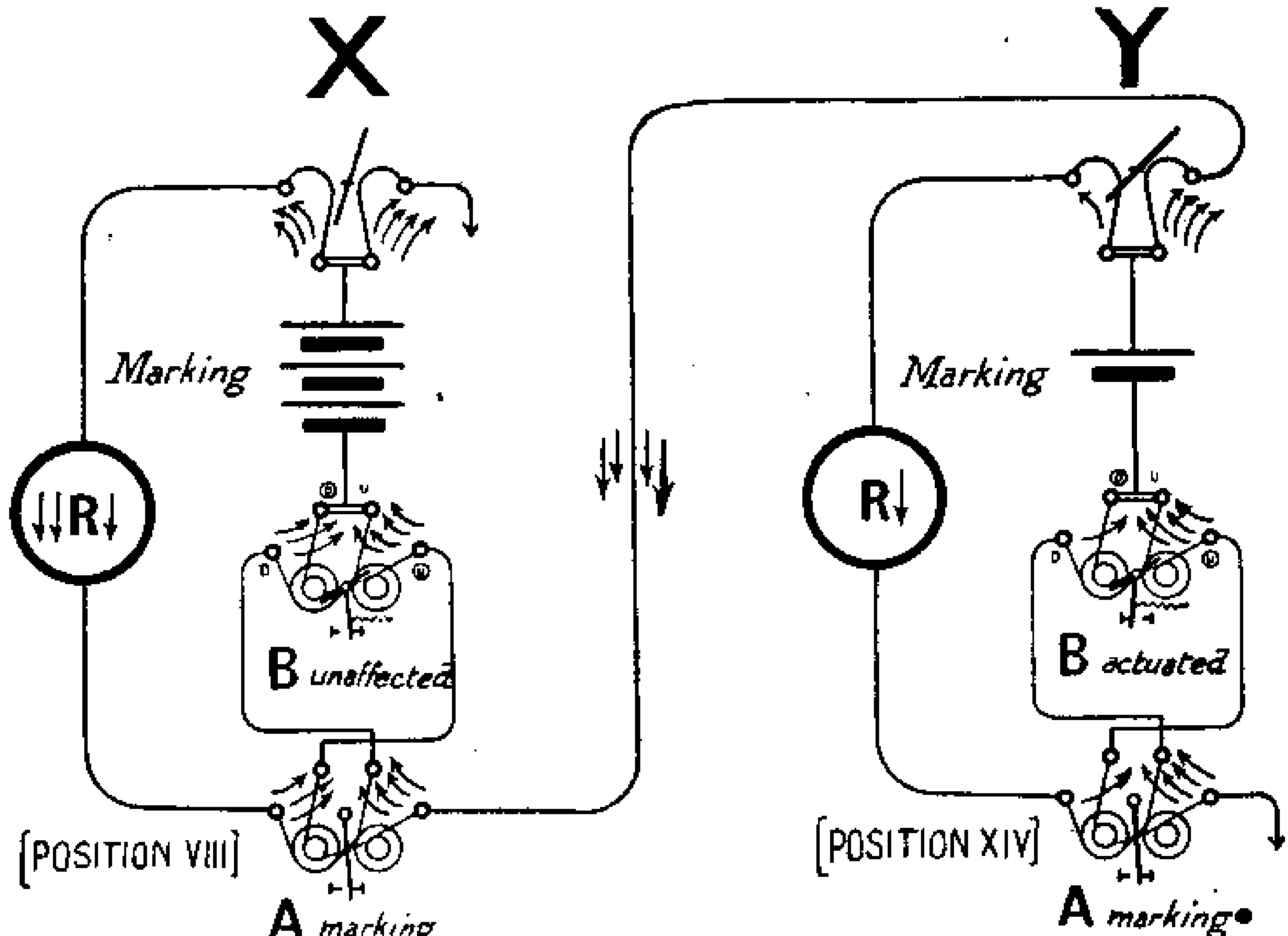

X
Y
Spacing
R
B unaffected
[POSITION III]
A spacing
Spacing
R
B actuated
[POSITION IX]
A spacing

Fig. 64.


X
Y
Marking
R
B unaffected
[POSITION VIII]
A marking
Marking
R
B actuated
[POSITION XIV]
A marking

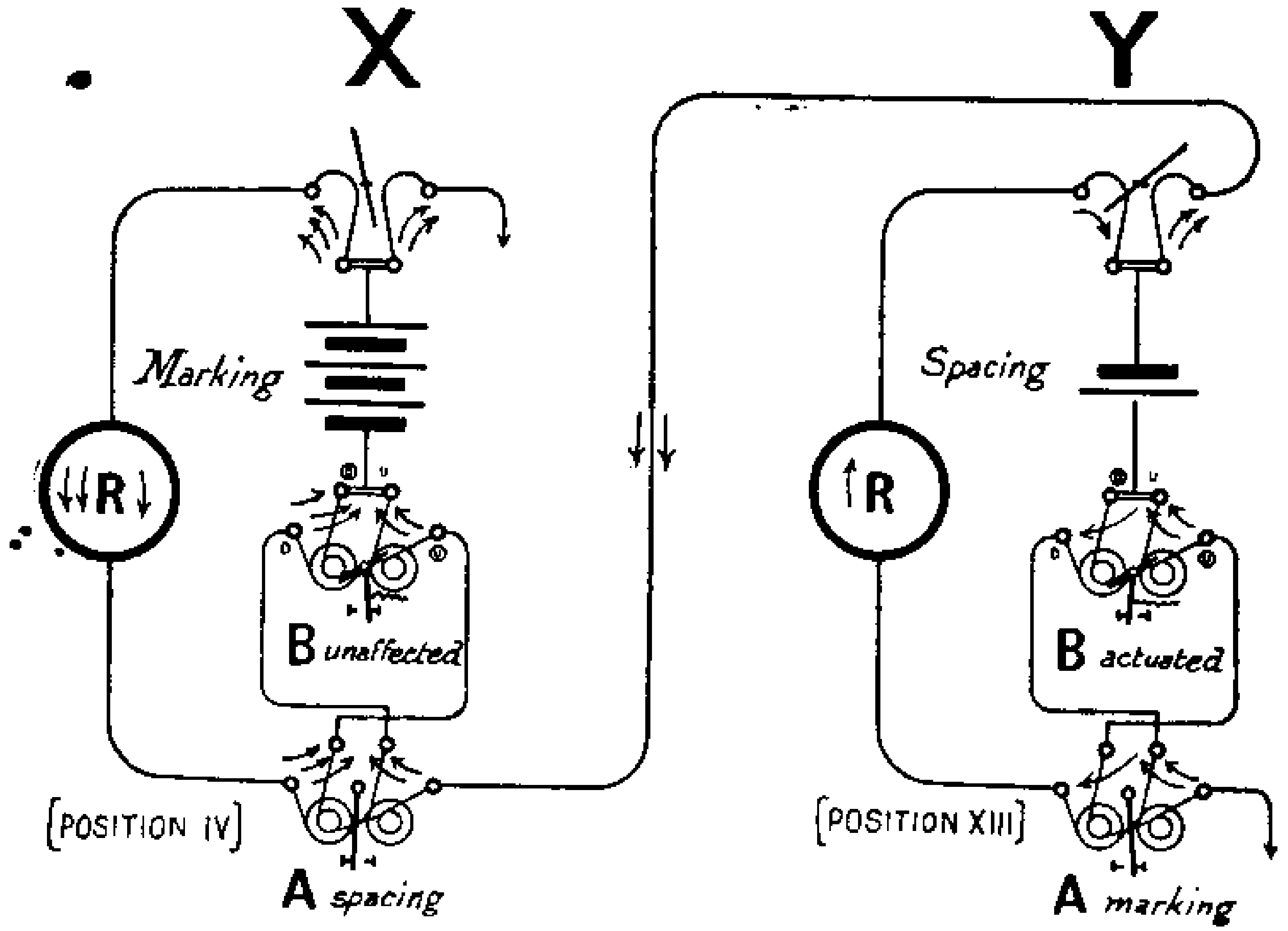

X
Y
Marking
Spacing
R
R
B unaffected
B actuated
[POSITION IV]
[POSITION XIII]
A spacing
A marking

Fig. 66.

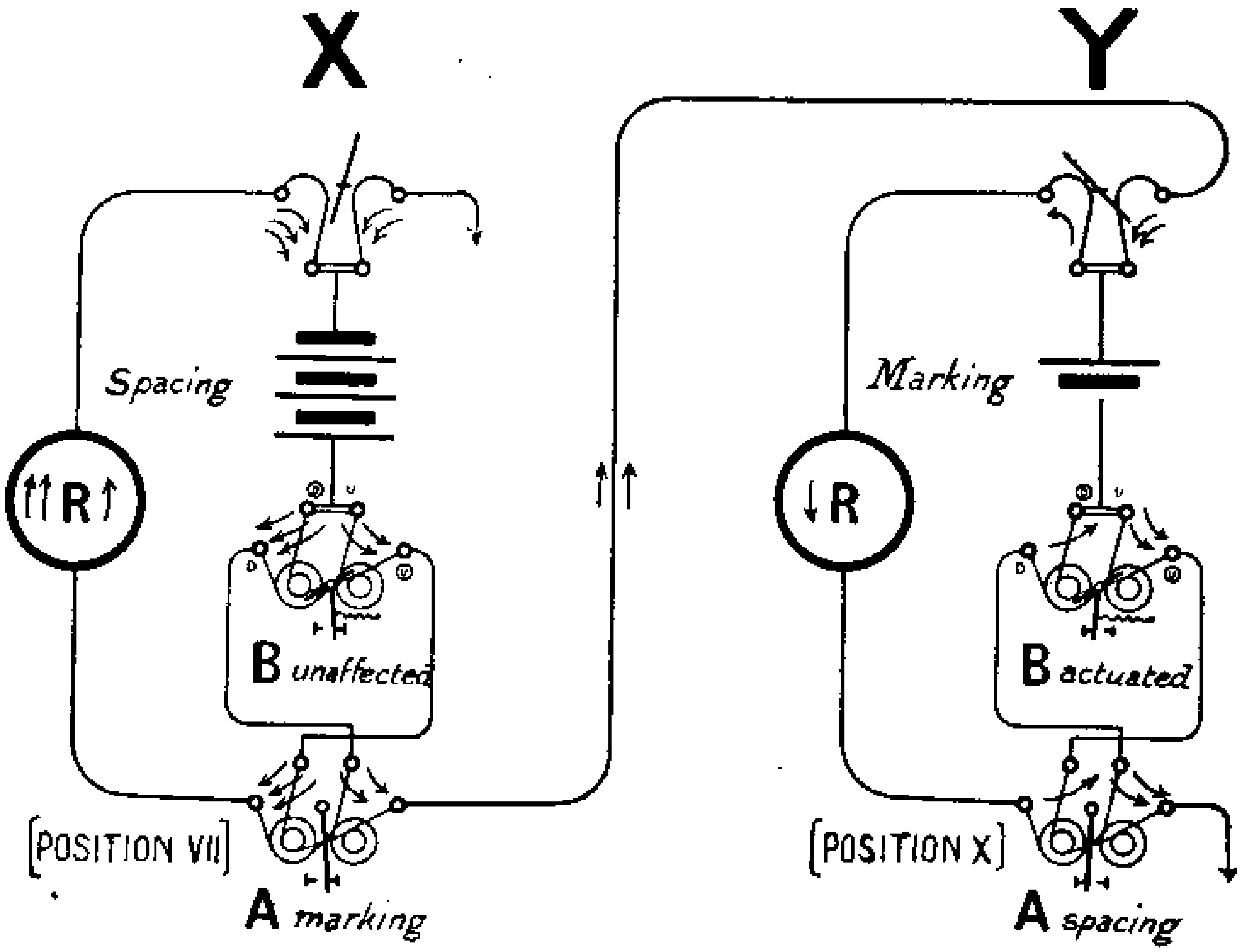

X
Y
Spacing
Marking
R
R
B unaffected
B actuated
[POSITION VII]
[POSITION X]
A marking
A spacing

Fig. 67.

their respective sending keys. These two figures correspond with positions III. and IX. and VIII. and XIV.

Figs. 66 and 67 show the full battery at one station opposed by the small portion at the other, the two A keys being in different positions. Comparing these cases with duplex, one may say that Y's battery is not merely opposed by X's, but is overpowered. Or the result of the opposition is that the line current is weakened to strength 2. At X the difference is 3 − 2 = 1, hence the B relay there is unaffected. At Y, however, the line and compensation currents are passing through both coils of both the relays, not differentially, but in the *same* direction, so that their effects are additive. The total strength is thus 2 + 1 = 3, which actuates Y's B relay. Again, comparing this with duplex, the absence of current in the line coils is replaced by one in the same direction as in the artificial circuit. As before, the directions of the currents are such that the movements of the tongues of the A relays at both stations harmonise with the positions of the A keys. These two diagrams correspond with positions IV. and XIII. and VII. and X. respectively.

Middle Position of Key.—In duplex working the key in its middle position causes a disconnection, the results of which we have considered. In quadruplex this disconnection at the keys is replaced by short-circuiting. Normally, the resistance of the key system in any working position is equal to the battery resistance plus the spark coil. When B key short-circuits, the resistance becomes = resistance of b + half that of tap coil. (Since the tap coil is equal to and placed in parallel with resistance of b_1 + spark coil.) When A short-circuits, although with regard to the battery itself the short-circuit is not absolute, yet as regards the path of the key system, the short-circuit is absolute and its resistance practically nil. Hence, the resistance between these points varies between (*a*) that of the whole battery plus spark coil (normal), (*b*) a value slightly less than this, and (*c*) nil. Obviously this is a better theoretical arrangement than the duplex one, as the variation is so much smaller.

Actual Joining-up of Quadruplex.—Up to the present we have considered the joining-up to be on similar lines to that of the duplex—viz., with a split at the relay and another at the galvanometer. This method, however, is departed from, as will be seen from Fig. 68. The battery is placed with one pole direct to earth, the other going *via* key system to the split at the B relay. The two portions into which the current divides then pass through the B and A relays and galvanometer in succession, one portion going to line and the other to the rheostat. At the down station a similar plan is followed, the line going from the galvanometer in both cases. This necessitates some crosses at the down office. Since the up station sends positive to line (marking), the other office must send negative: the batteries have, therefore, to be reversed at the A key. Since different polarities are applied to the split of the relays, the line and compensation circuits have to be crossed. This is effected by crossing the two upper terminals of the galvanometer. The deflections on the latter are in the same direction as those on the up instrument. These crosses are indicated in Fig. 68 by asterisks, and it will be noticed that two other crosses, the lower terminals of gal-

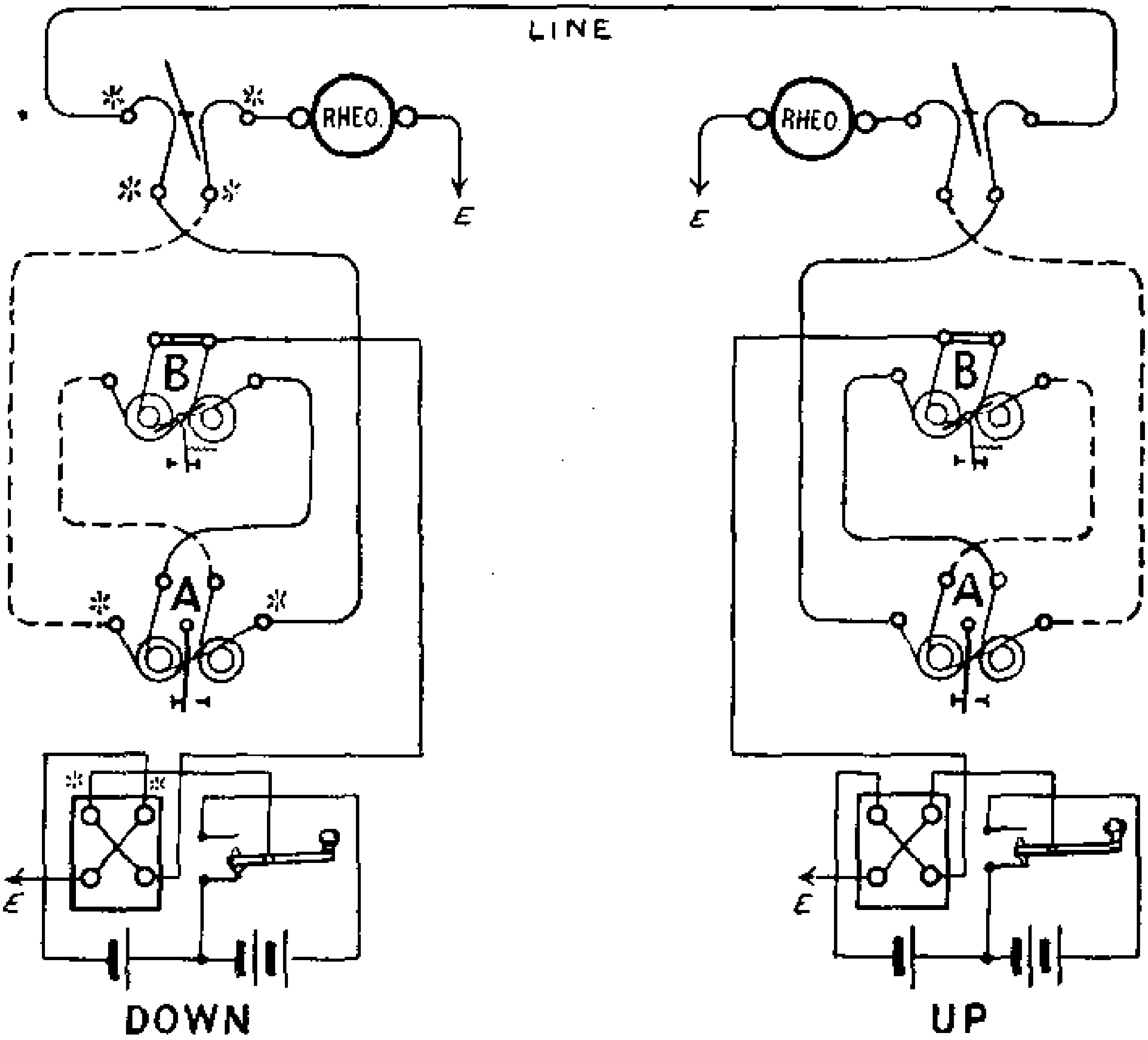


Fig. 68.—Quadruplex: skeleton of circuit.

vanometer and the terminals D and (U) of the A relay, are shown. These two latter cancel each other, as far as this skeleton diagram is concerned. The reason is explained on p. 77 in connection with Fig. 70. In Fig. 68, for clearness, the compensation circuits at the two stations are indicated by dotted lines.

The complete diagram of connections for working on the increment system is given in Fig. 69 (up station). It will be seen that this is the old form, employing the relaying sounder, a 4-terminal reversing key, and an old-pattern incrementing key. The resistance coil *r* has a value equivalent to that of the tap coil T, plus the spark coil S. By means of the two-way switch this is substituted for the key system, so that the distant station can balance with his galvanometer needle vertical.

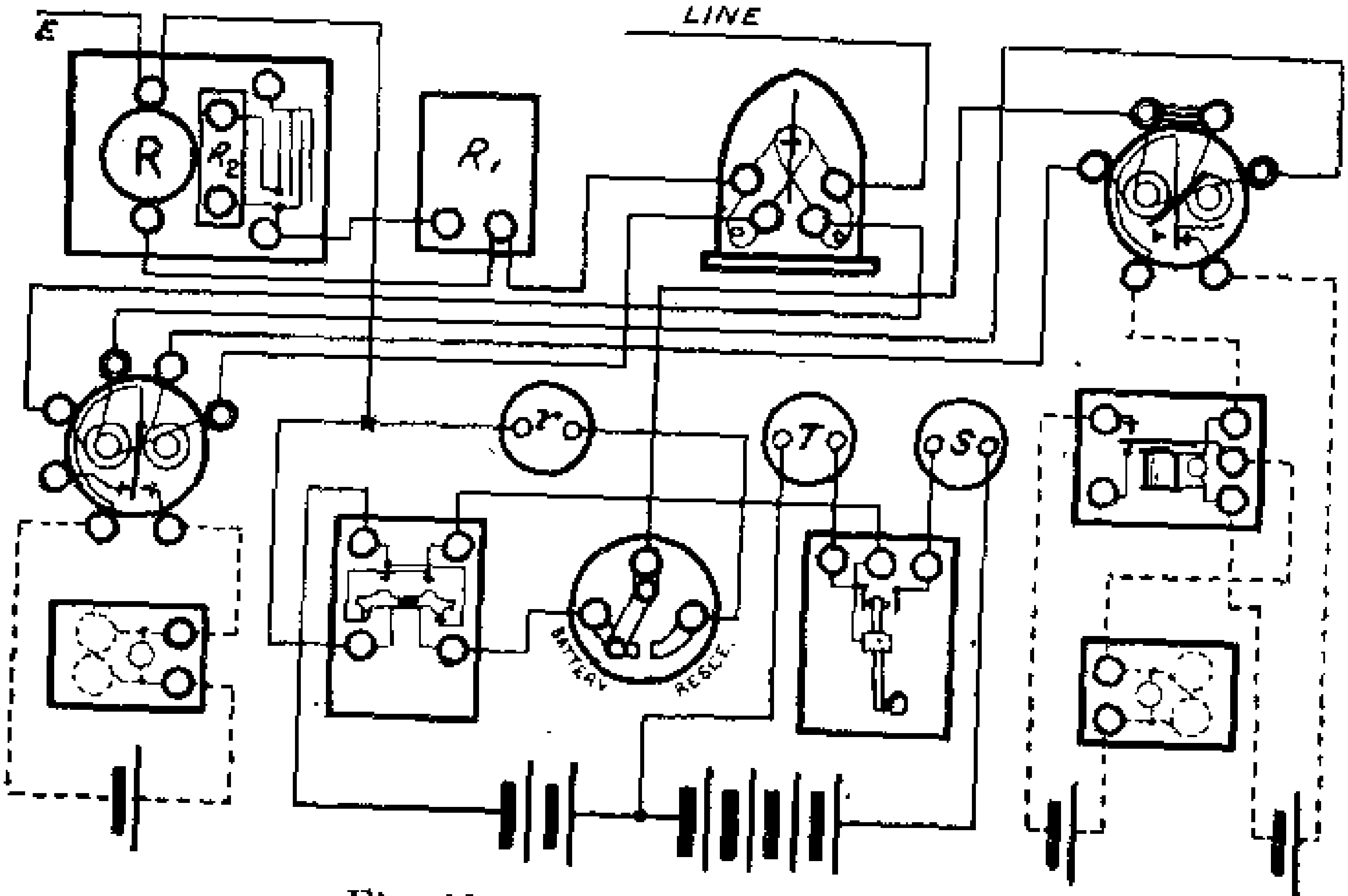


Fig. 69.—Quadruplex: old form.

Quadruplex: Standard Arrangement.—As previously stated, Fig. 69 is the arrangement which has been in force for some years. The introduction of secondary batteries, however, has led to the employment of high-resistance sounders, and these, in their turn, have led to the simplification of the B local circuit. Further, since quadruplex working, or even duplex (using A side only), may not always be practicable or desirable, a switch has been added to the equipment to enable the wire to be worked as a simple sounder circuit at will. The standard diagram is given in Fig. 70.

Simplification of B Local Circuit.—The new sounder has its coils wound to 1,000 ohms and shunt 10,000 ohms; its effective resistance is, therefore, 900^{ω}. It is identical with the old 20^{ω} instrument but for the winding. Since the 1,000-$^{\omega}$ coils occupy the same space as the 20^{ω}, the wire must necessarily be finer and of much greater length. As the self-induction increases with the square of the number of turns, the new instrument has a larger coefficient of self-induction than the old. This quality admits of its being placed directly in the local circuit of the nonpolarized relay without the intermediation of the relaying sounder. A condenser is placed across its terminals, and when the break occurs (due to the middle position of the distant A key) the condenser discharge, which is in the same direction as the extra current from the sounder coils, serves to bridge it over and prevent the release of the armature and the consequent splitting of the signal. A resistance is placed in series with the

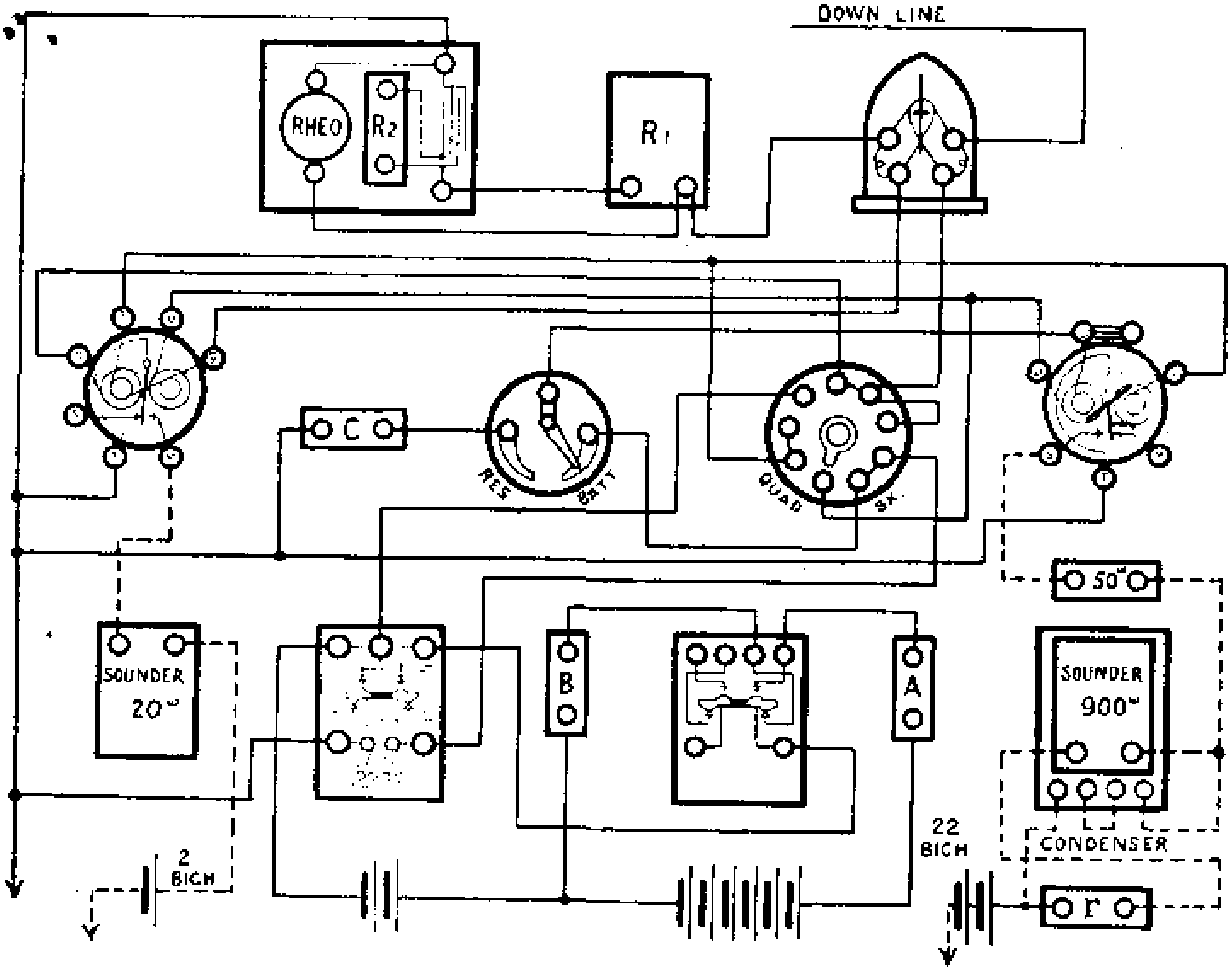


Fig. 70.—Quadruplex: standard arrangement, primaries.

sounder and the condenser *across the two.* A second resistance is placed in series with the whole.

The condenser really consists of two 4-mfd. *condensers mounted* in a single case. As joined up its capacity is 2 mfds. On long circuits a larger capacity may be necessary, and this can be arranged, either 4 or 8 mfds.

The relay employed is known as the "C" form of non-polarized relay. It is a larger instrument than the one which we have

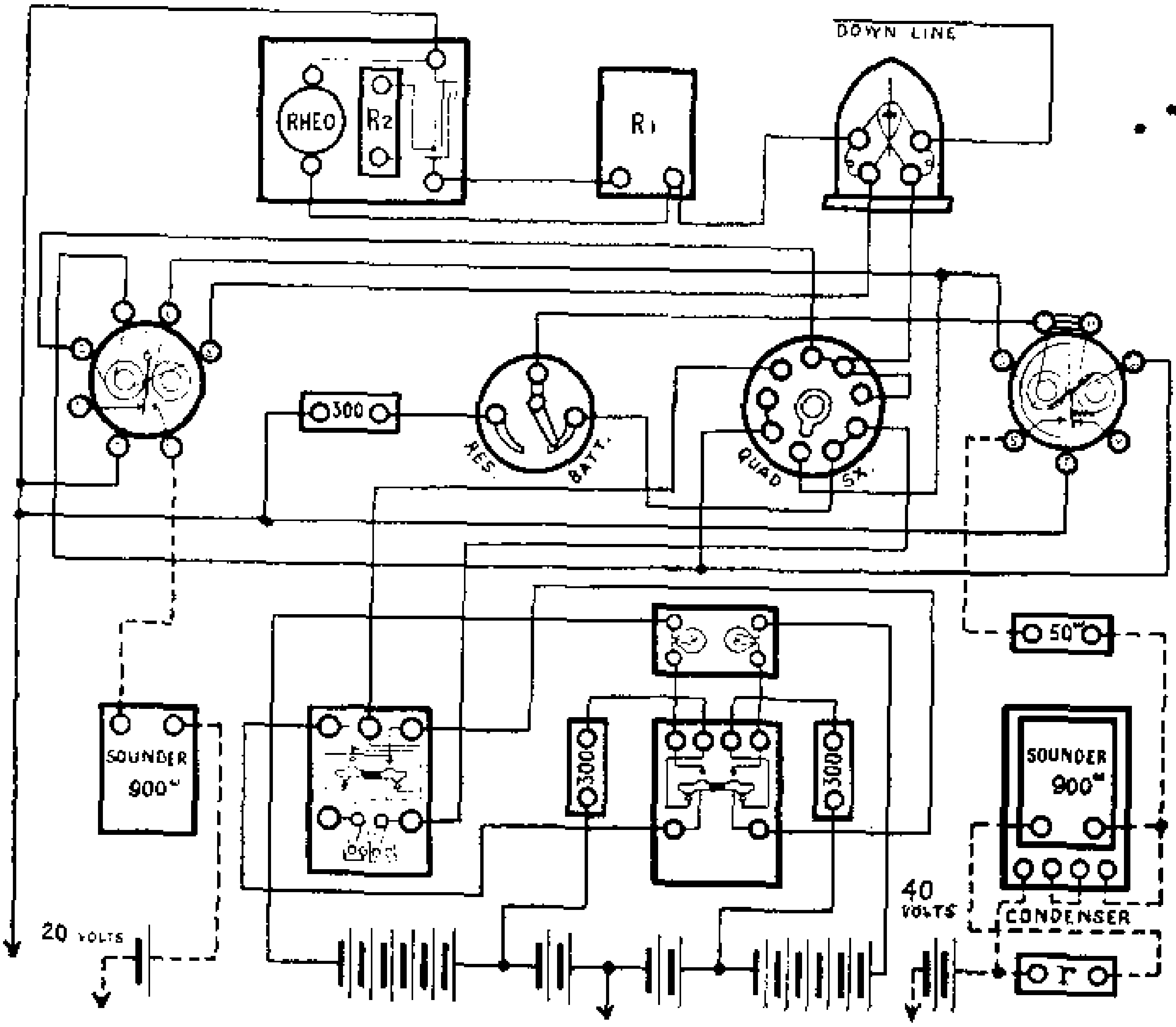


Fig. 71.—Quadruplex: secondaries.

described (Figs. 57 and 58), and has larger cores, and is wound *to 100ω each coil. Both contact screws* are platinum-tipped and brought to separate terminals. The tongue and left-hand contacts are in use.

Further Details.—It will be seen that the key on the A side is an ordinary double-current one with *switch. The contacts* of all these keys are now made adjustable, so that by simply short-circuit the sending battery or cause a disconnection at will. In the present case the former is, of course, arranged for. Several patterns of key have been tried on the B side, and the present one ("key, reversing, 6-terminal") is practically identical in its main arrangements with that on the A side. Its four contact-springs are, however, taken to four separate terminals, and it has no switch. Its lower contact-screws (adjustable) are arranged to short-circuit.

The 9-terminal switch introduced to "simplex" puts the line directly through to the A key, thence to terminal D of A relay, and short-circuits the outer terminals of B relay.

These connections are for an up office. At a down station the reversals already mentioned in connection with Fig. 68 are necessary. The crossing of the two lower terminals of galvanometers and of terminals D and (U) of A relay, although effecting no cross between themselves, are necessary in order that the line may be brought to the A key in the simplex position of the switch.

The resistance coils A and B are metal-cased, the former of 50^{ω} and the latter equivalent to the resistance of the B battery *plus* 50^{ω}. The resistance C is equivalent to the resistance of the whole battery *plus* 50^{ω}. The coil *r* is that known as the "battery-resistance coil," having three coils of 100, 200, and 400 ohms.

Universal Working.—Fig. 71 gives the connections when secondary batteries are employed. The resistances in the lower power battery leads are metal-cased, each of 300 ohms. Those in the higher power leads are 16-candle-power 100-volt incandescent lamps, and the earthing resistance is also 300 ohms. For a down office the four crosses previously mentioned are necessary.

Automatic Working on A Side.—The A side is frequently fitted with transmitter and receiver in order that Wheatstone working may be resorted to when necessary. The receiver then takes the place of the A relay, its coil straps being removed. The necessary alteration in the connections for primary and secondary batteries is shown in Figs. 72 and 73.

Additional Increment for Automatic Working.—The old difficulty of quadruplex working, as we have seen, is the splitting of the B side signals at the reversal of the current by the A key.

tendency is intensified. Assume the B key to be depressed and the transmitter to be running without slip. A series of alternating currents is sent out, and the reversals are so frequent that *the effective current may be reduced below the value normally* attained in hand-working. On a circuit with but little margin, therefore, the running of the transmitter interferes with the signals on the distant B relay. It is therefore arranged, under some circumstances, that the turning on of the transmitter switch shall increase the B side battery power. That is, when ordinary

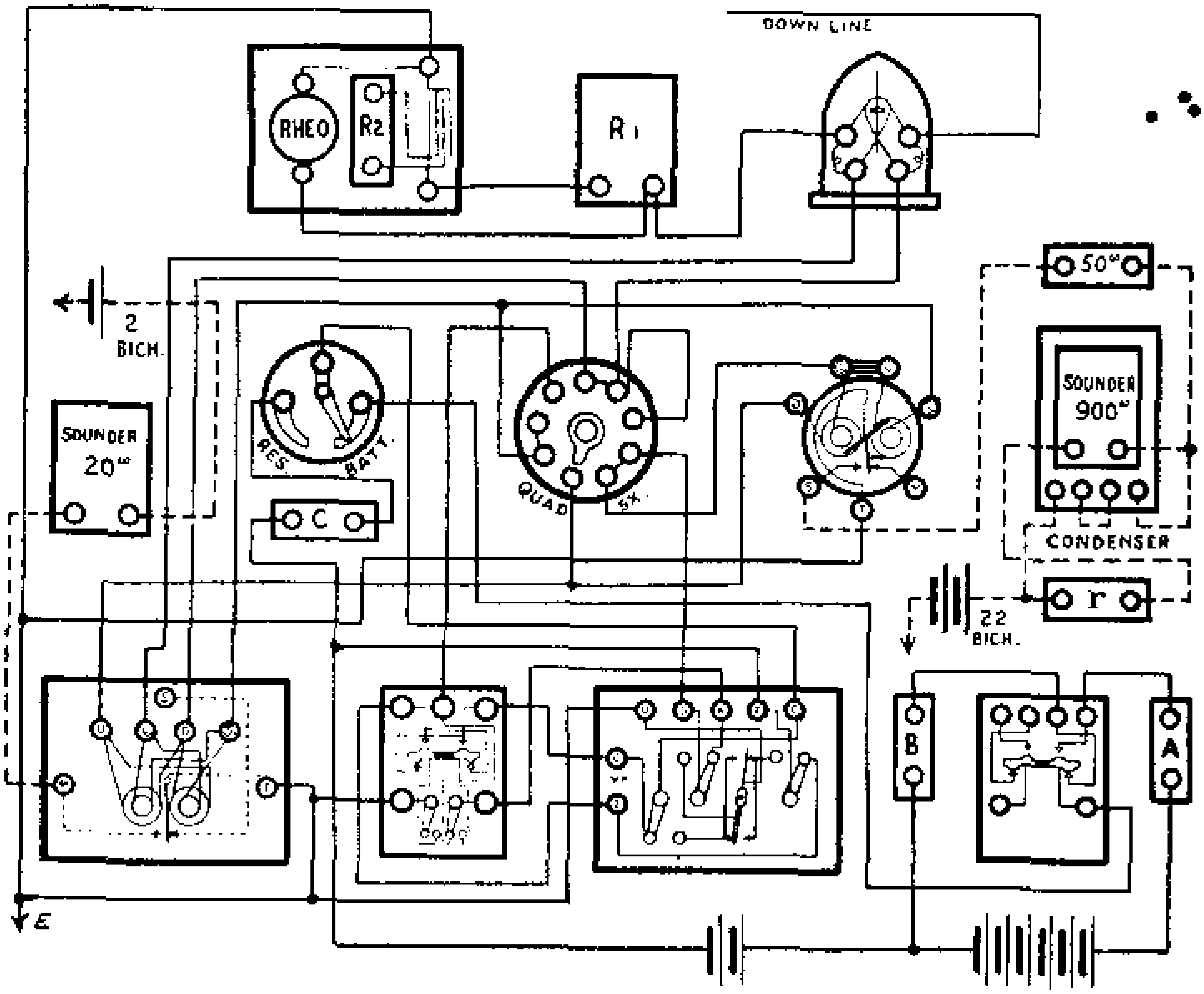


Fig. 72.—Quadruplex: Wheatstone on A side, primaries.

key working is in progress on the A side, the depression of the B key brings in the normal increment—*i.e.*, increases the current to about three times the A value. The movement of the transmitter switch brings in an additional increment, so that when the B key is put down under these circumstances the current is increased to about four times the A value. How this is effected is shown in Fig. 74. With primary batteries the U terminal of the transmitter is taken to earth through the coils of a neutral relay. Whenever the transmitter, therefore, is running, this relay is actuated, and closes the circuit of a relaying sounder, whose armature then brings in an additional incrementing battery to the *B* key. When the transmitter is at rest and key-working is in progress the relay is not actuated, as its left-hand front terminal is earthed direct. Between its right-hand front terminal and the transmitter, however, is a resistance coil of 50 ohms, a similar value to that of the relay, so that the resistance in circuit shall not vary. The self-induction of the relaying sounder prevents the release of its armature at the reversal of the current.

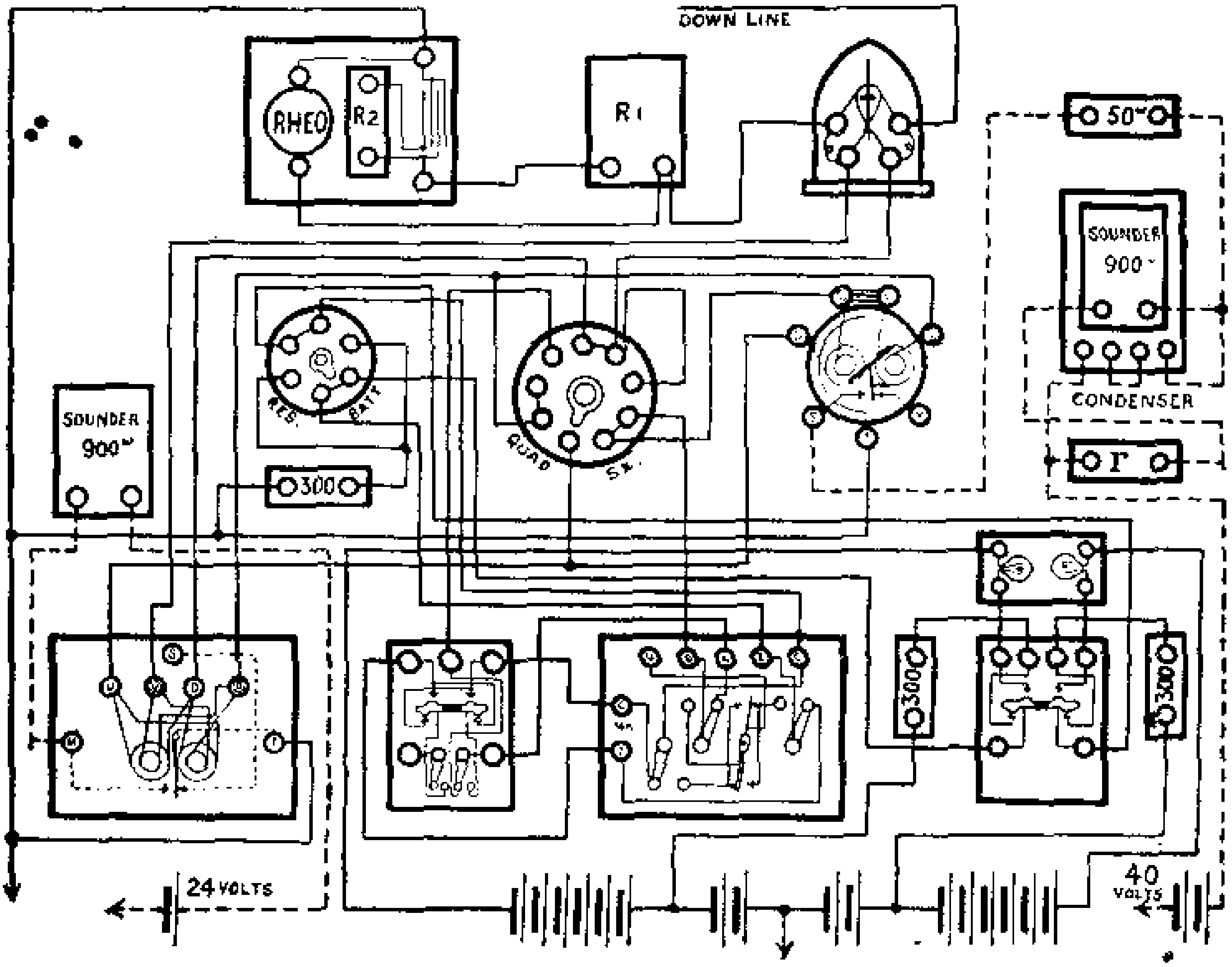


Fig. 73.—Quadruplex: Wheatstone on A side, secondaries.

In universal working, when the negative battery is sending, the positive is idle, and *vice versâ.* The additional increment is then obtained by utilising this idle pole of the battery to actuate the neutral relay, which closes an automatic switch (see Fig. 168). The two levers are permanently connected to the two outer terminals of the B key, whilst the two ordinary increment poles are brought to the outer, and the additional increment poles to the inner, contacts of the switch. The extreme left-hand terminal of the transmitter is connected through a resistance block of 3,000 ohms to one side of the relay coils, the other side being to earth. When the transmitter is not in

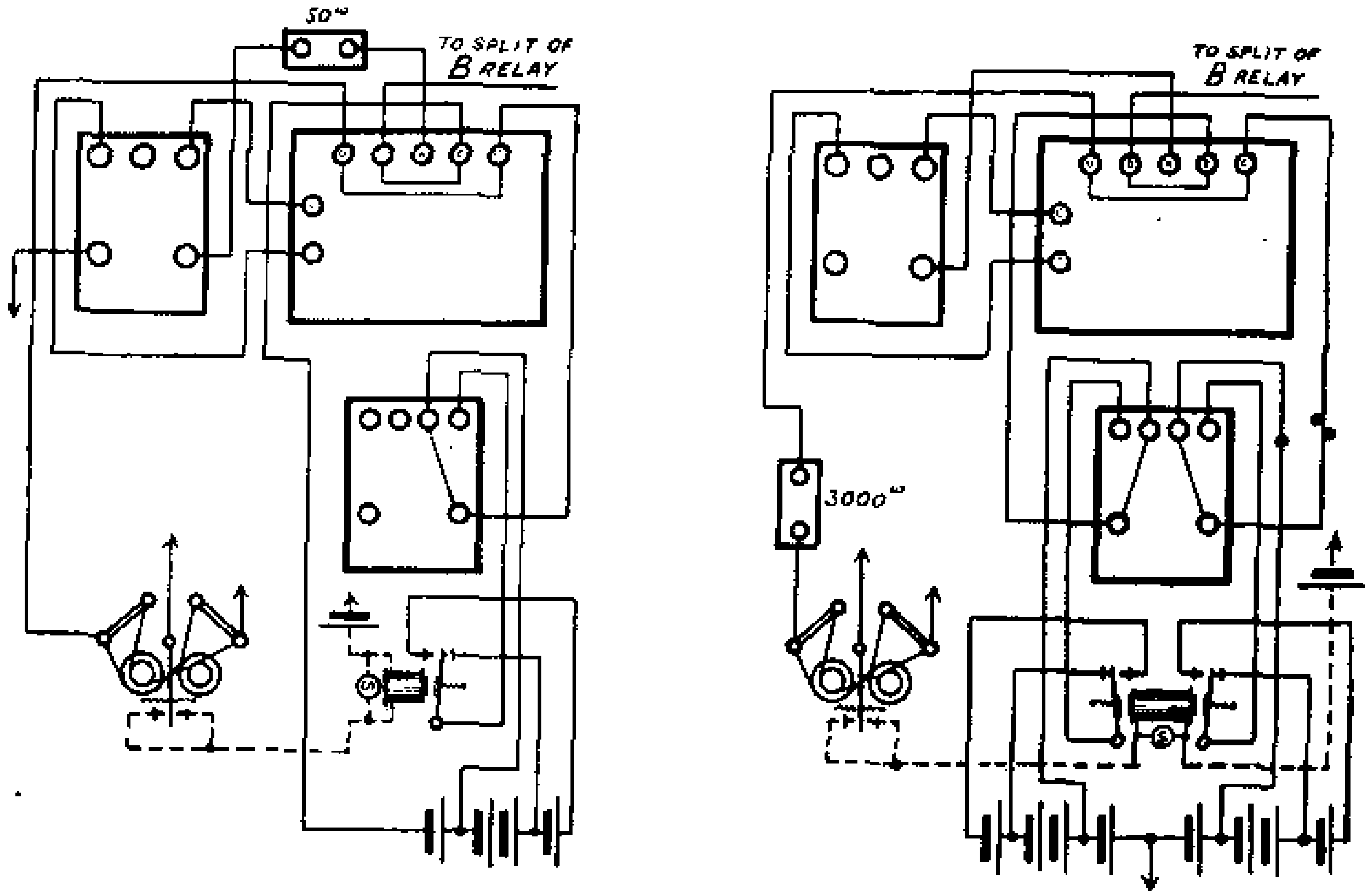


Fig. 74.—Incrementing voltages.

use this left-hand terminal is disconnected, and the poles of the ordinary incrementing battery are brought to the B key through the outer contacts of the switch. When, however, the transmitter is running, the otherwise idle pole of the main battery actuates the neutral relay. The switch closes, and brings into use the additional incrementing battery. The self-induction of the coils of the switch keeps the levers continuously over whilst the current is being reversed.

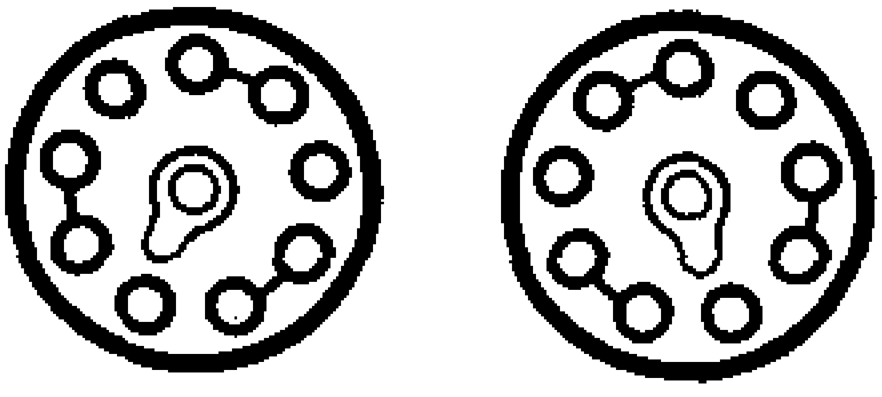


Fig. 75.—Connections of 9-terminal switch.

Decrement Working.—For decrement working the two wires on the back of the B key—*i.e.*, the A and B voltages—in Figs. 70 and 72 are reversed. This is for primary batteries. For secondaries the two inner back terminals are crossed with the two outer on the B key in Figs. 71 and 73. In all cases the wire must be disconnected from terminal S of the B relay, and brought to

CHAPTER V.

AUTOMATIC TELEGRAPHY.

By the methods of the two preceding chapters we enable two or four operators to be sending *at once*. Taking the speed of hand-signalling to be 40 words per minute, this gives us a speed of 80 or 160 words per minute for the circuit. But the line is capable of transmitting perfectly formed Morse signals at much higher rates than this, and a speed of 400 or 500 words a minute is possible. For dealing with such a speed as this, machinery is obviously necessary, hence its name, the *automatic* system. It will be seen that this method attacks the problem of efficiency in quite a different way to that of duplex and quadruplex. The latter simply set up additional channels for hand-working; the automatic raises the working speed of the channel itself.

The system then replaces the hand-worked key and sounder by mechanical means for sending and receiving. The two instruments thus employed are the transmitter and the receiver, whilst a third one, the perforator, is engaged in the preparation of the work before the latter is ready to be passed through the transmitter.

The action of the perforator is entirely mechanical. In it a white paper ribbon of a somewhat substantial quality is perforated to correspond to "dots," "dashes," and "spaces." This ribbon thus prepared is passed through the transmitter and determines the direction and duration of the sent-out currents. These currents, in their turn, actuate the receiver, a delicate direct ink-writer which records the signals on a rapidly-moving paper slip. The maximum speed of hand-working does not exceed 40 words per minute; with the automatic system and instruments of the latest type any speed up to 500 words a minute can be attained.

Perforator.—The general appearance of this is given in Fig. 76. Details of the perforator proper, a small rectangular brass casting on which is mounted the punching mechanism, are given in Figs. 77 and 78. Five circular horizontal punches are so placed as to be actuated in the desired or key, *a*, *b*, and *c*. When *a* is struck, punches 1, 2, and 4 perforate the paper in a single vertical line. When *b* is depressed punch 2 only responds, whilst the depression of *c* causes 1, 2, 3, and 5 to perforate the slip. These three sets of holes correspond to a dot, a space, and a dash respectively. It will be seen that the perforations due to punches 2 and 3 are smaller than those made by the other three, and that one of these central holes is always punched, sometimes 2, so that a length of slip emerging from the instrument has a continuous central row of holes. This series of centre perforations serves as a rack by which the slip is propelled through both perforator and transmitter.

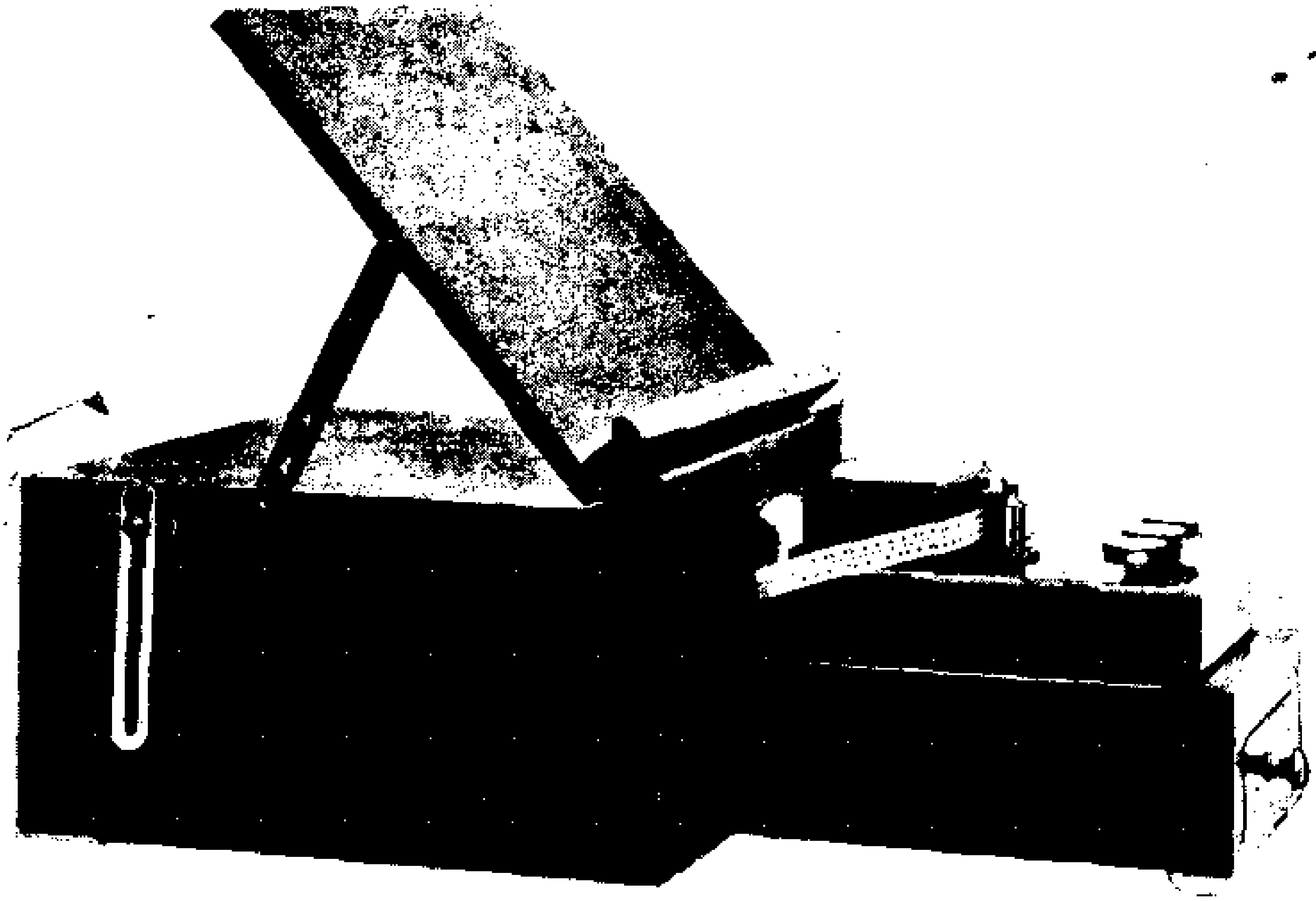


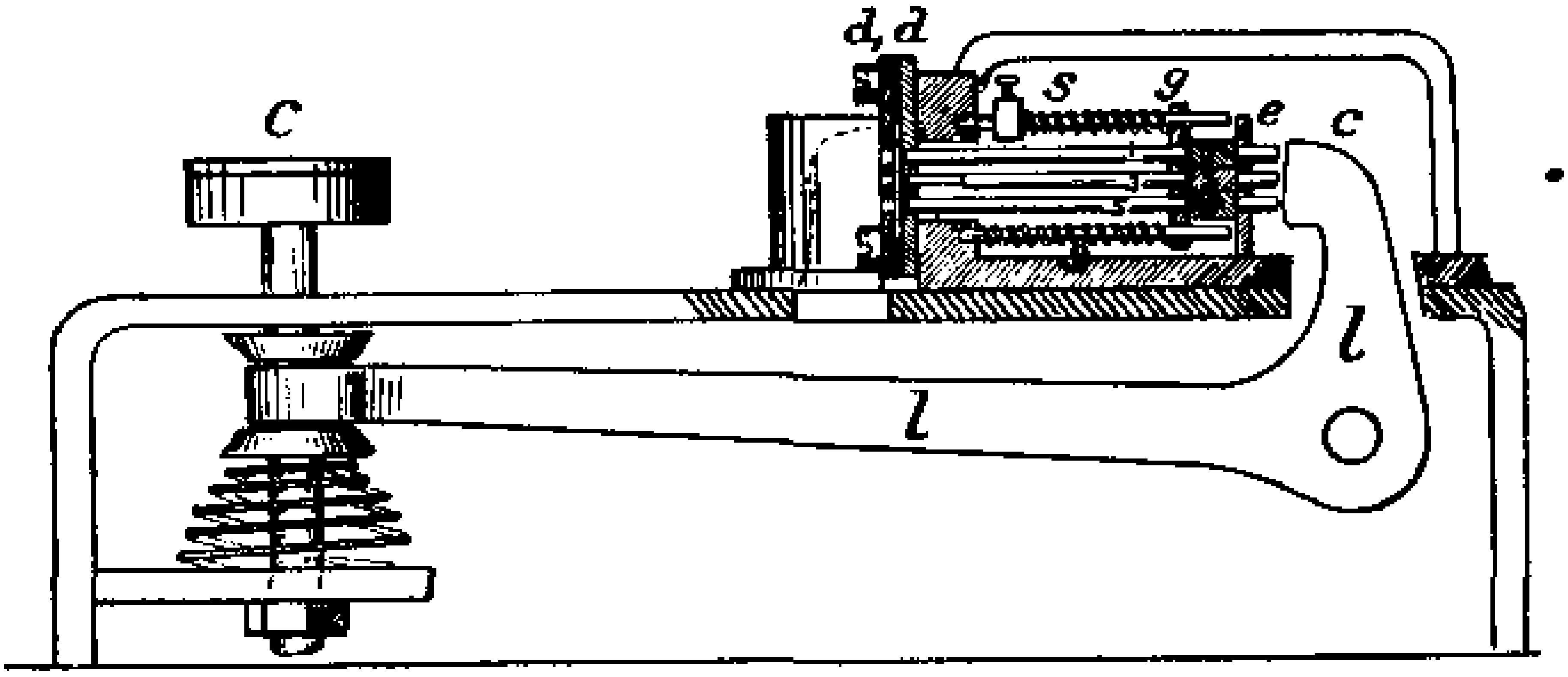
Fig. 76.—Wheatstone perforator.

The rise of each key after depression is caused by a spiral spring beneath the base. At the same time another spring causes the paper to be fed forward. In the case of a dot or space this movement is equal to the distance between two spacing perforations; in the case of the dash the movement is twice as great. Thus, by means of the dot and dash keys, letters are formed; and, by the spacing key, each letter is separated from its neighbour. To separate words the spacing key is struck twice.

It will be seen from Fig. 77 that each key is connected with one end of an iron lever, *l*. There are necessarily three of these levers, and they are pivoted beneath and at the back of the perforator, their farther ends being bent at right angles and brought up through the base to the back of the punches. One only is shown in the figure. When the long arm is lowered by the depression of *c*, the short vertical arm will move and force the three punches to the left. Fig. 78 shows that the order of the keys and levers is not the same, *a* and *b* being crossed under the base. Thus, the depression of *a* actuates the centre lever, and *b* the first or left-hand one. Fig. 77 gives full details of the five punches. They are carried by two plates *d* and *e*, front and back, and immediately in front of *d* is another, d_1, with perforations exactly corresponding to, and in exact alignment with, those in *d*. The two, *d* and d_1, are slightly apart, so that the paper slip may pass between them. When a punch is forced forward it perforates the paper and enters the hole in plate d_1, carrying with it the perforation, which drops into a receptacle beneath. Each punch has a squared shoulder at the rear, and in front of this squared portion is a brass plate, *g*, of oval shape. All the punches except No. 2 pass freely through this plate, as do also two rods, one above and one below the punches, each of these rods carrying a spiral spring, *s*. To be more correct, the plate *g*, when moved forward, slides over the rods and over any punches which may not be actuated. The springs *s* force the plate *g* backward when the key rises; *g* butts against the shoulders, and by them withdraws the punches. When any punch is urged forward the shouldered portion necessarily takes *g* with it, leaving behind the unactuated punches. The plate, sliding along the upper and lower rods, compresses the spiral springs by which the punches are promptly brought back when the key is released.

The back plate *e* has seven holes, whilst the front *d* has but five. Punch No. 1 has a shoulder of double width, which carries two pins at the rear. These two latter work in the two uppermost holes of *e*. This punch is therefore actuated by both *a* and *c*, but not by *b*. Punch No. 2 is permanently fixed to the oval plate *g*, the others, as we have seen, simply passing through it. Its shoulder, like that of No. 1, is of double width, and carries two pins which move in the two left-hand holes of the central row of *e*. This (spacing) punch is required to move alone when spacing, and also to be actuated when either dot or dash is required. When moving alone it is actuated by *b;* when moving with others to form a dot it is urged forward by *a.* Punch No. 3 is actuated by *c* (dash), and its shoulder-piece, acting on plate *g,* carries punch No. 2 with it. Nos. 4 and 5 are actuated by *a* and *c* respectively.

The paper-moving arrangements are shown in Fig. 78. A lever *h* is pivoted at *i* and normally lies beneath the upper ends of *a, b* and *c,* which are cut away to allow of this. Another



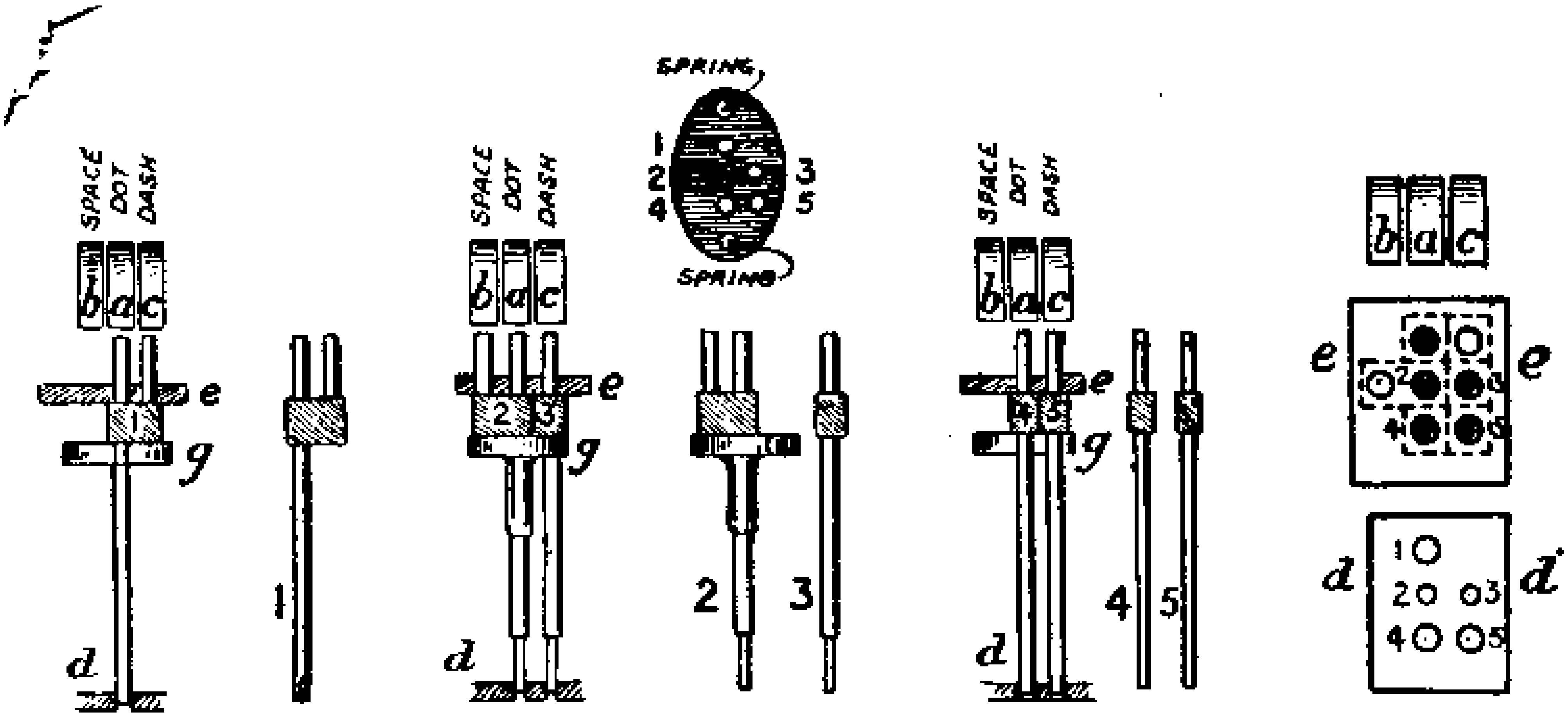


Fig. 77.—Perforator details.

lever *j* is attached to *h* by the screw *f,* and both *h* and *j* are kept normally drawn against the stop *k* by a flat spring *r, k* serving as a fulcrum. The other end of *j* carries a pawl, *m,* engaging with the star wheel *p.* The pawl is pressed on to *p* by a flat spring passing up from beneath the base, and ending in a loose grooved roller, *n.* The star wheel, in its turn, engages with the central row of holes in the slip. When a key is struck, moves to the left, drawing with it the pawl, which then slips over a tooth of the star wheel. When the key rises, the spring *r* brings *j* and *h* back to their original positions, and the pawl, in returning, forces the star wheel forward. The play of *j* to the left is limited by a curved piece or lever *t*, so that on the return of the former the star wheel shall propel the paper forward a single space. This occurs when *a* or *b* is depressed. When, however, *c* is struck, so that the perforation takes up a double horizontal portion of the slip, the latter necessarily requires to be shifted a double space. An attachment is therefore made between the other end of *t* and the lever of *c* beneath the base, so that when *c* is depressed it takes this end of *t* with it. The other end is raised, and *j* is then free to move over to the stop *q*, slipping over two teeth of *p* in its journey. On its return it thus propels the paper forward two spaces. The adjusting arm *w* is to limit the play of the pawl to the right. That is to say, it determines the distance between the central perforations. The proper adjustment is that which gives 120 spacing holes in a foot of slip. The frame carrying the star wheel can be moved by the tail piece *x*, so that *p* shall be clear of the space between the two front plates. This allows of the easy insertion of a new slip.

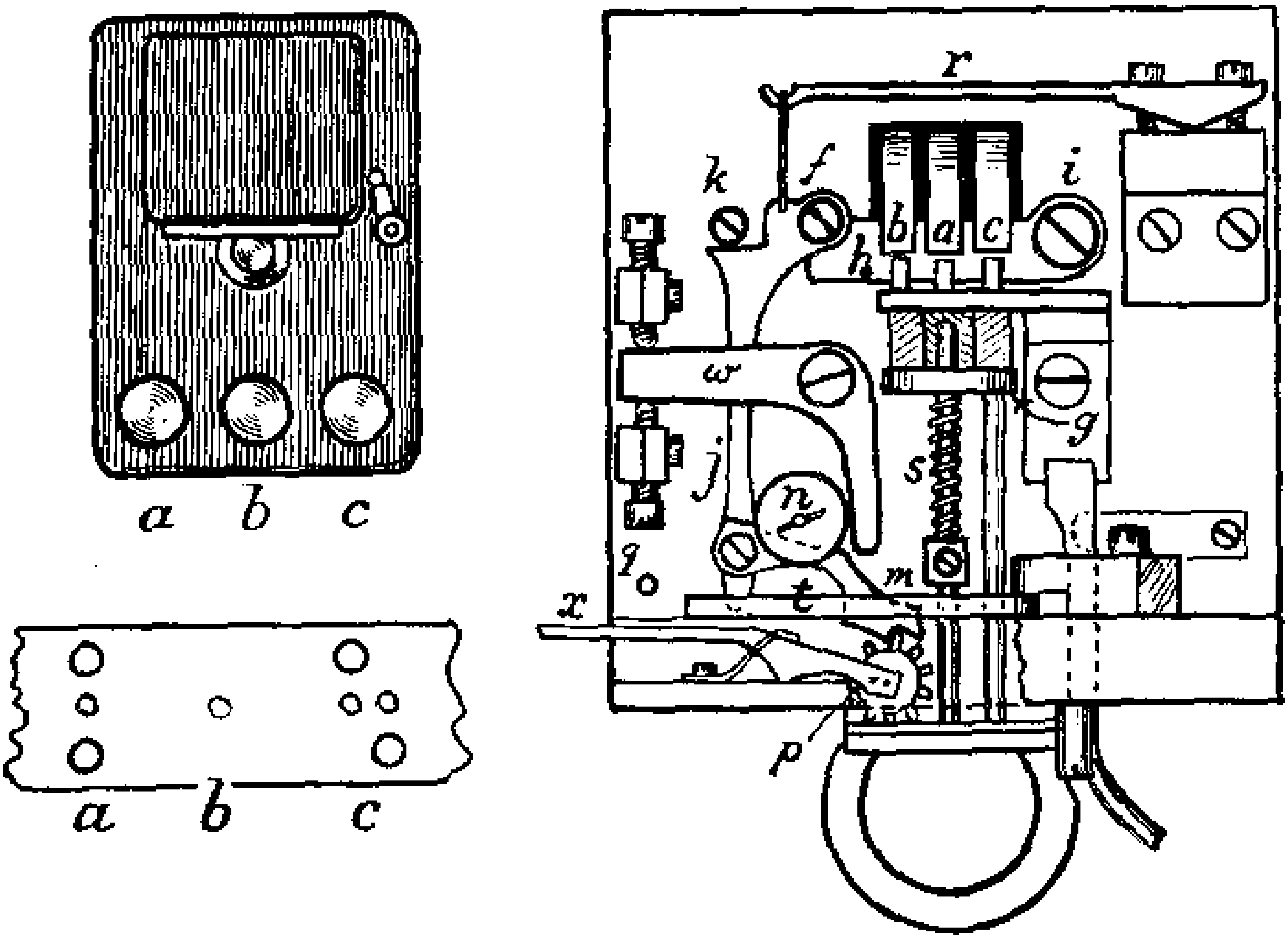


Fig. 78.—Perforator details.

Pneumatic Perforator.—At large offices where pneumatic pressure is available this source of power is utilised for the manipulation of the perforator. The effort required for punching in the ordinary way is considerable, whilst, in this adaptation, all the work to be done by the fingers is simply to open a small valve, thus admitting the air, which then drives down a piston. This, in its turn, depresses the key of the perforator.

There are thus three keys or tappers controlling three pistons, and an ordinary perforator is placed so that its keys are immediately beneath the pistons. The pressure is sufficient to punch several slips at once, so that as many as four can be prepared at the same time. Further, a double set of pistons and valves may be actuated by the same set of tappers, so that two perforators may be employed, giving a maximum of eight slips. The latter arrangement, the double pneumatic perforator, or "double decker," is illustrated in Figs. 79 and 80, and its details given in Fig. 81. The front of the

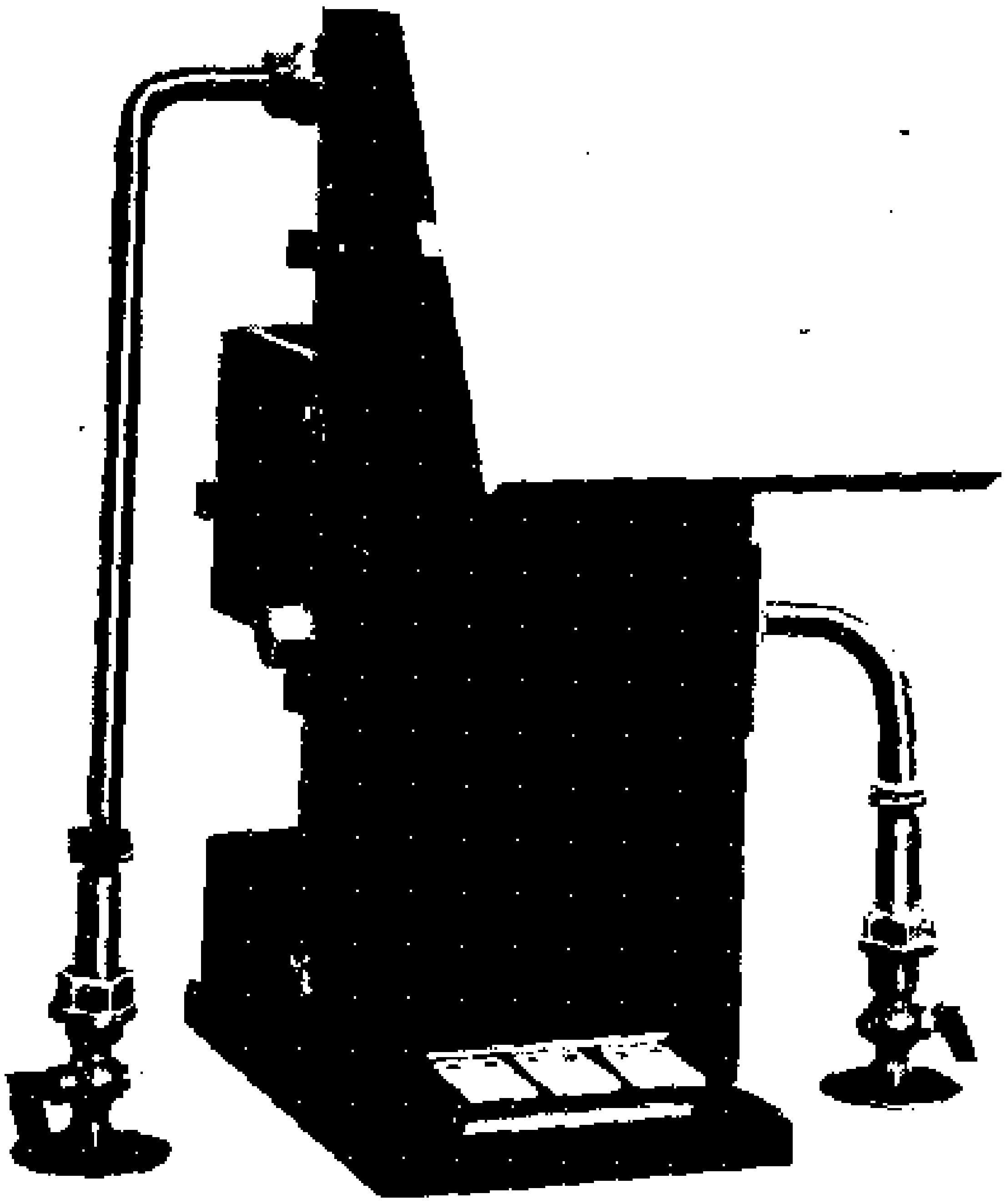


Fig. 79.—Pneumatic perforator.

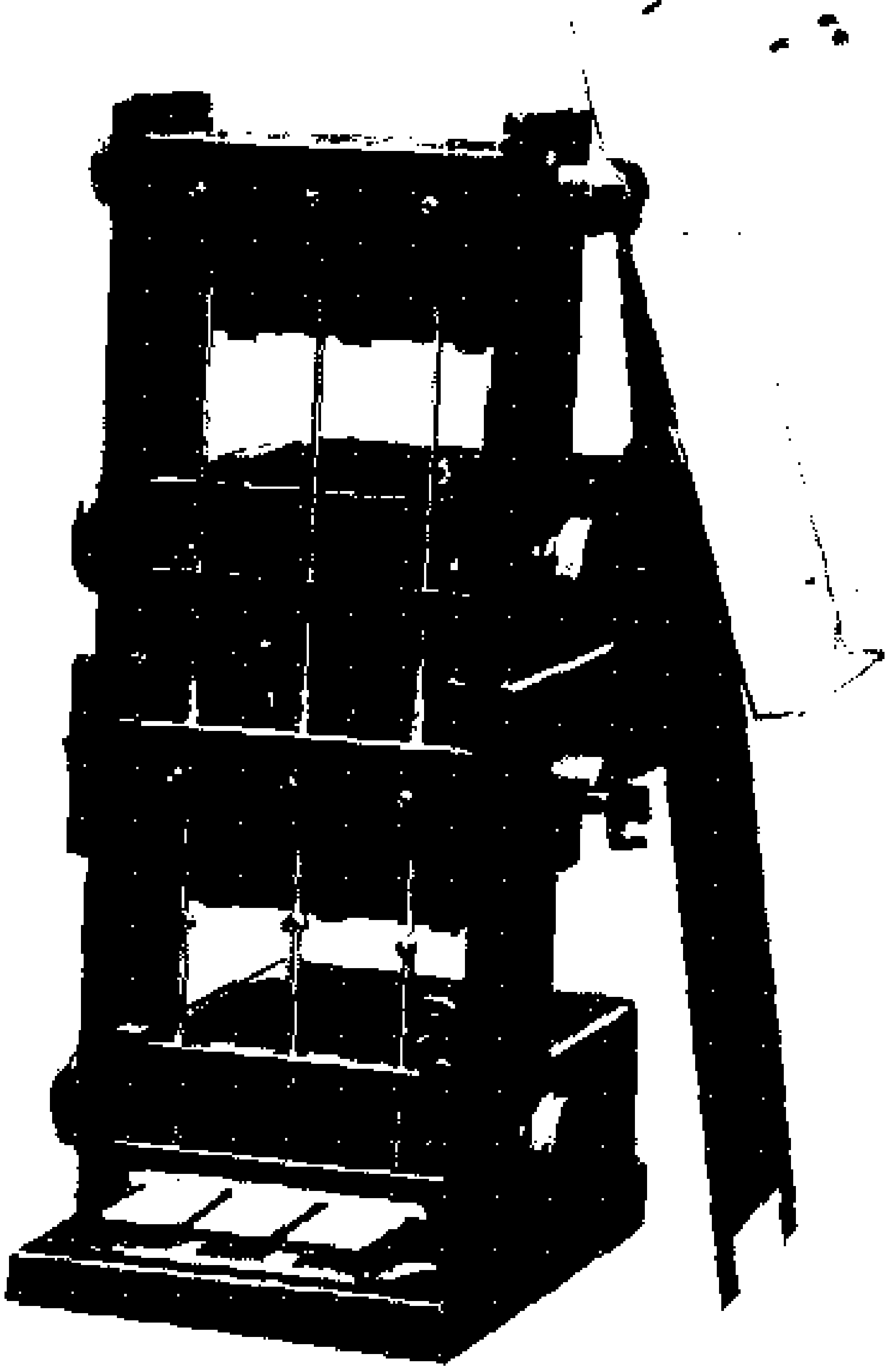


Fig. 80.—Pneumatic perforator.

covered by a metal plate, and from the top of this an adjustable slope depends for the accommodation of the message forms. These are taken off in Fig. 80, so as to expose the interior. Three thin steel rods, attached at their lower ends to the three tappers, carry the valves admitting the air to the pistons. One of the pistons and its valve are shown separately in Fig. 81 in their normal position on the left, and with the tapper depressed on the right. B is the piston working in the short cylinder C, and carrying on its under side a stout rod or plunger which works through the cylinder cover. A spiral spring normally forces the piston upwards, so that the end of the plunger is about flush with the cover. If the compressed air be admitted above the piston, it will, of course, urge the latter downwards, overcoming the upward thrust of the spring. To admit the compressed air is the office of the valve P. This valve slides up and down in a smaller cylinder or cylindrical passage. The

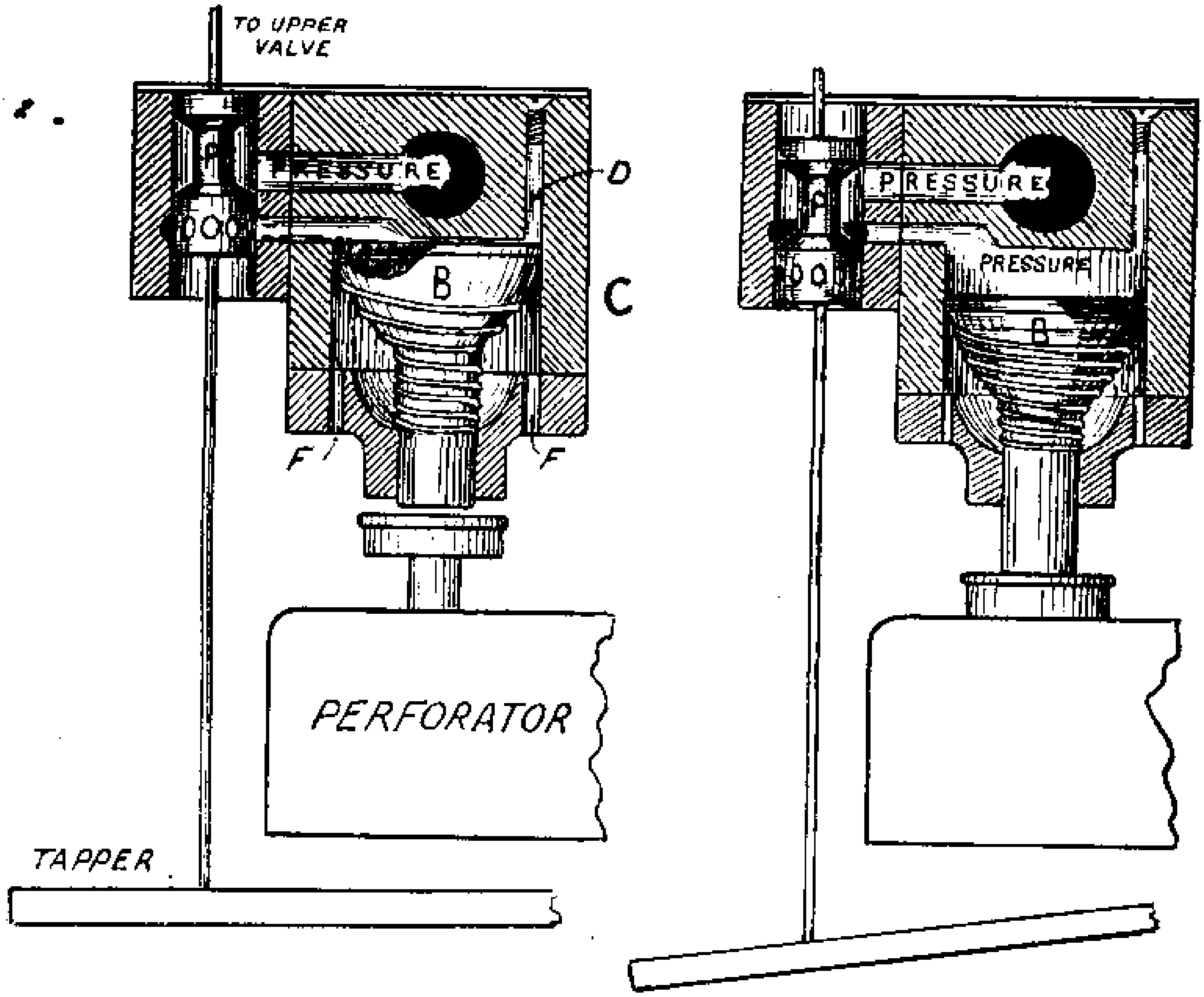


Fig. 81.—Pneumatic perforator: details.

central portion of P is turned down to a much smaller diameter, so that there is an annular space between the walls of the cylinder and this central portion. This space is always in communication with the compressed air supply through the circular channel shown in black.

When the key is depressed P moves downwards to the position shown on the right. By this movement communication is opened between the pressure supply and the space above the piston by means of the annular space round the valve and the channel leading to B. The piston is forced down and the plunger strikes the key a smart blow, thus operating the punches. When the key is allowed to rise P returns to its old position, cutting off the pressure. The lower part of the valve is pierced all round with holes, leading by the interior of the valve, which is hollowed out at this region, to the open air. The cylindrical channel in which P moves has a groove cut entirely round its circumference, and this groove communicates with the passage leading to the back of B. When the valve is in its normal position the series of holes in its lower part put the space above the piston in communication with the outer air. Hence, as soon as the valve rises, the compressed air at the back of the piston escapes, and the latter is forced upwards by its spiral spring. Holes are drilled in the cover of cylinder C so that the air below the piston may escape when B moves downward, and may re-enter when it moves upward.

The larger the area of the piston the greater the force of the blow; hence the area of the pistons varies according to the work they have to do.

Creed's Keyboard Perforator.—This is an ordinary typewriter keyboard, the depression of whose keys perforates the slip with the required letters. The operator, therefore, need not be a telegraphist, but must be a typist. The actual work done by the finger is simply to put down the key; the necessary combination of punches is then actuated by pneumatic pressure. Thus a single movement takes the place of a maximum six, which are required when a figure, followed by its "space," is punched on the ordinary perforator.

Kotyra Keyboard.—This also is an ordinary typewriter keyboard, arranged to actuate three electro-magnets which in their turn depress the keys of an ordinary perforator, or the valves

Beneath the whole series of keys is a revolving pinion, so elongated as to form a long cylinder, whilst the underside of each key carries a rack. When any key is depressed, its rack engages with the pinion which rapidly carries the key backward for a short distance and then releases it. The key then resumes its normal position. Each key also carries a metallic brush, and in its backward journey the brush passes over a series of contacts which complete the circuit of the three electro-magnets in the required order. Thus, if key L be depressed, it closes the circuits of the magnets in this order: space, dot, dash, dot, dot. Similarly with all the others—the space signal preceding the letter. The electro-magnets then drive down the punches and perforate the slip as in the ordinary manner.

Transmitter.—This is shown in Fig. 82 and the electrical arrangements in Fig. 83.

The star-wheel K, driven by the clockwork, is so placed that its teeth pass through a slot in the brass platform shown and rise a little distance above the upper surface of the latter. The teeth, therefore, engage with the central row of perforations in the prepared slip. Another wheel, L, shown end-on to the left of the same figure, is notched at the centre of its periphery so as to allow the star-wheel to engage with and drive it. L actually touches the platform only by its sides, the central portion of its circumference being of somewhat smaller diameter, so as not to press upon the slip. At the same time it is sufficiently near to prevent the latter from rising off the teeth of K. On either side of this reduced portion it is still further reduced—the object of which we shall see later. The paper slip is thus drawn through the transmitter. A rocking lever R, also actuated by the clockwork, is constantly reciprocating upon its centre and carries two pins upon its front face. Two bell-crank levers, A and B, are pivoted as shown, and two spiral springs, *f* and *g*, are attached to them. These springs tend to force the upper vertical arm of B and the lower arm of A to the right. Pinned to the ends of the horizontal portions of the levers are two rods, S and M. The upper extremities of these pass on either side of the star-wheel, through slots in the brass platform, M being nearer the frame of the instrument. Further, as regards the direction of the movement of the slip, S is a little in advance of M, the latter being in line with the centre of K. The object of the two to the ends of S and M when their alternate rise is permitted by the movement of the rocking beam.

The compound contact lever is pivoted about its centre and plays between four contact stops. The upper portion is fastened to the main fitting, but is insulated from it. The right-hand contact stops are connected to the negative and the left to the positive pole of the battery. When the upper end is towards the right, "copper" is to the down line and "zinc" to up. When the lever is in the opposite position the battery, of course, is reversed.

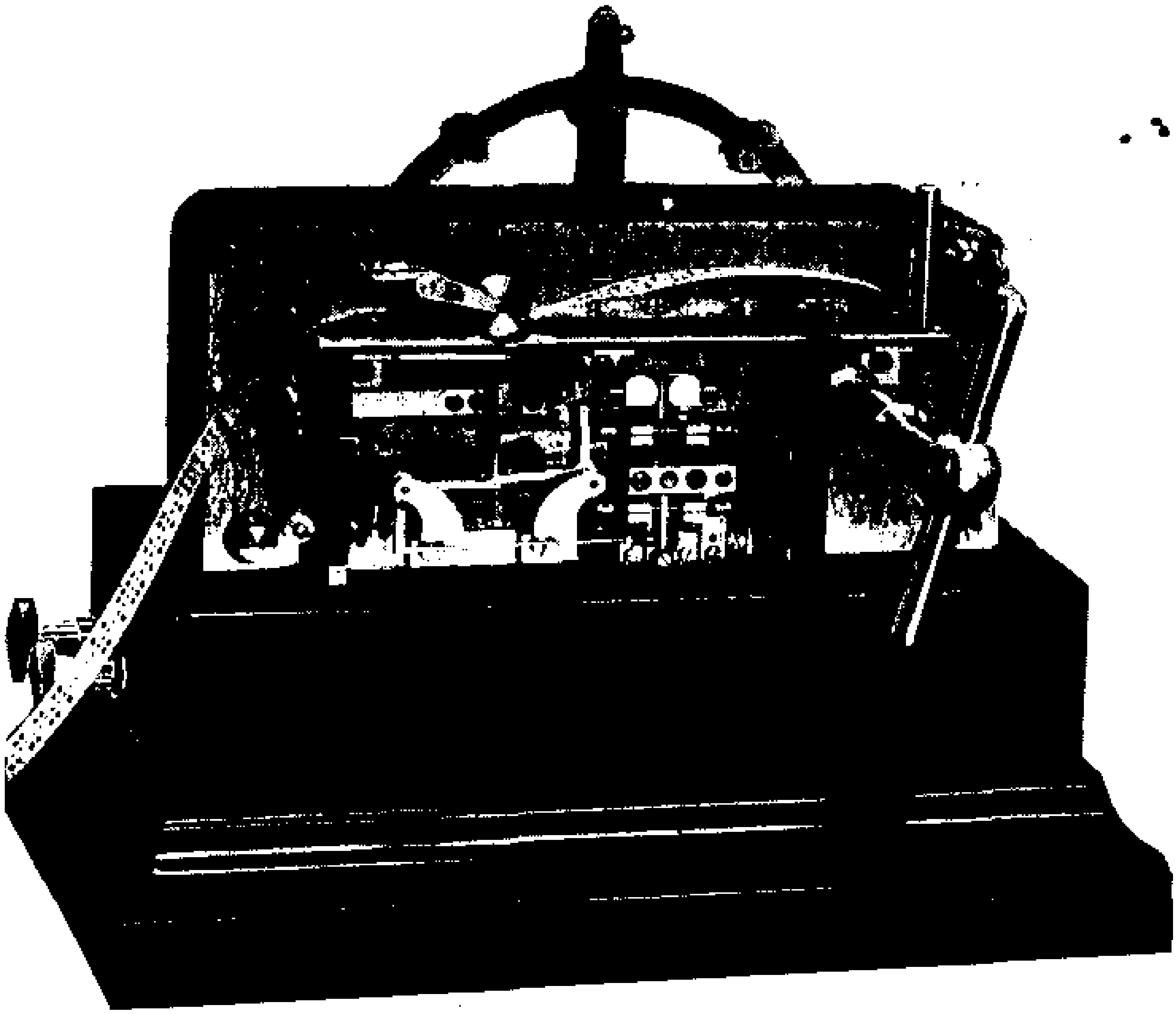


Fig. 82.—Wheatstone transmitter.

It will be seen that if the spiral springs were allowed to act, the right-hand one would actuate its crank and force the upper portion of the lever over to the right. Similarly, *f* would move it to the left. The two pins in the rocking beam, however, alternately prevent and allow of this action of the springs.

That is, when the right-hand pin descends, B is carried downwards with it, whilst the left-hand pin rises and allows *f* to thrust the contact lever to the left. Similarly, when the movement of the beam is reversed A is carried downwards and *g* is allowed to thrust the lever to the right. On the top of the latter, which is brought to a sharp edge, is a jockey-wheel which is pressed down on this edge by a spring. The effect of this is that the contact lever cannot remain in the central position. In fact, the levers only thrust it beyond the centre, and the jockey-wheel completes the movement. Hence, when the transmitter is running without slip, the rods S and M are free to rise alternately, the contact lever oscillates between the two sets of contacts and a succession of reversals passes to line.

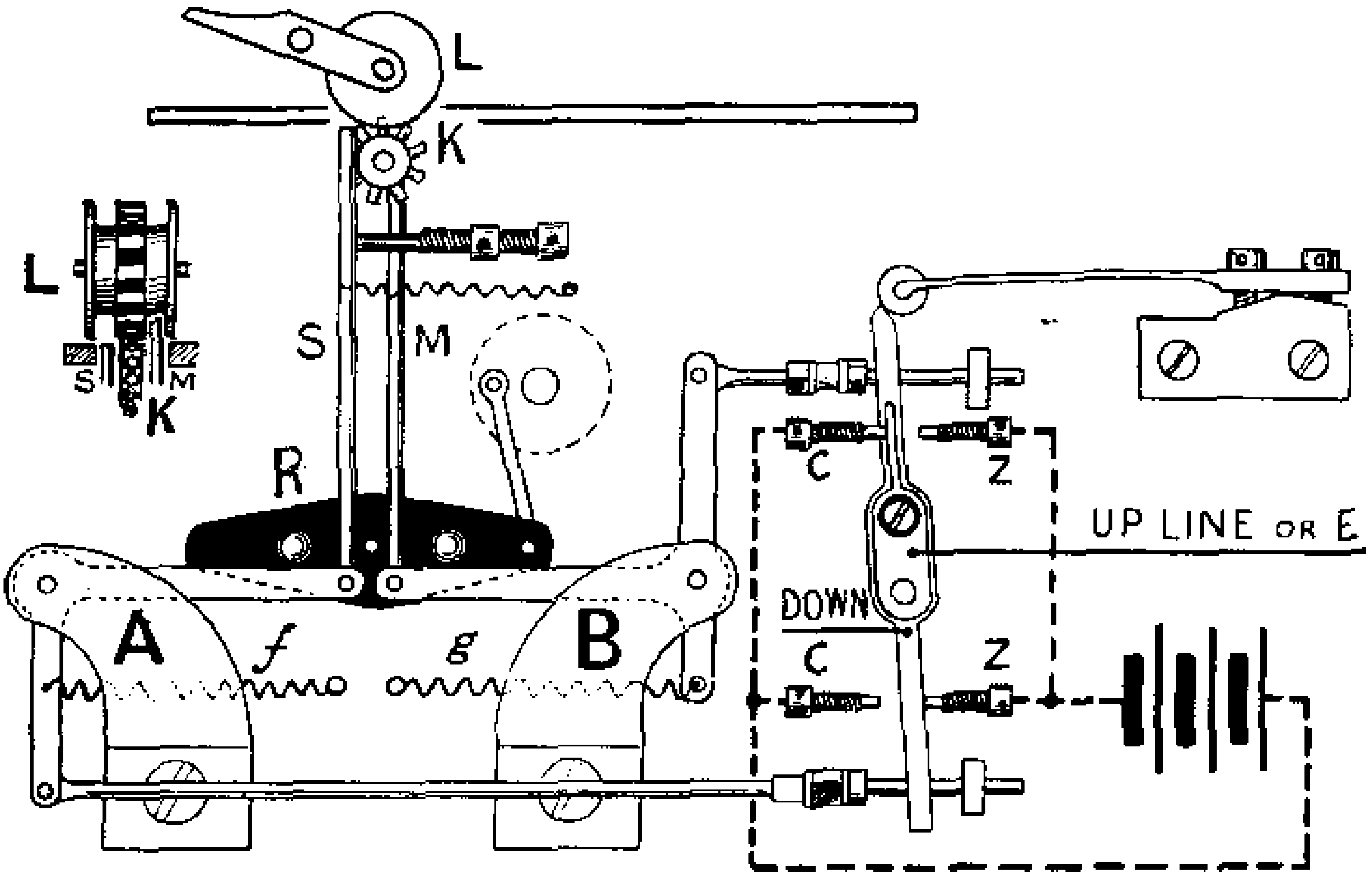


Fig. 83.

Now, let us suppose a length of slip to be inserted, which has only the central row of holes punched in it. This will be drawn through by the star-wheel. When the rocking lever allows the rods S and M to rise, the latter find their way above the platform barred by the unpunched slip. They are therefore unable to complete their upward journey, and cannot move the contact lever. The latter then remains in the position in which it was last placed, and a permanent current goes to line. (This current is invariably a spacing one, since the last signal sent is always in that direction.) Thus the prevention of the rise of the rods by an unpunched portion of slip prevents the moving of the contact lever and the reversal of the current previously flowing.

We will assume that another slip is inserted, perforated with a succession of dots, without intervening spaces, as at *x*, Fig. 84. When the first of the upper row of holes comes over M, the latter is rising, and is free to pass through the hole. It does so, moves the lever to the right, and puts on a current in the marking direction. M now descends, and S rises. The paper having advanced, the first hole of the lower series is immediately over S, which is likewise free to move. In completing its motion it causes the lever to move to the left, thus putting on the current in the spacing direction. When S descends, M is again rising, and encounters the second of the upper holes, with the result that the marking current is again put on, and so on. The effect, therefore, of such a slip is precisely the same as if the transmitter were running without slip—*i.e.*, the alternating upward motion of the rods is unimpeded by the paper, and a succession of

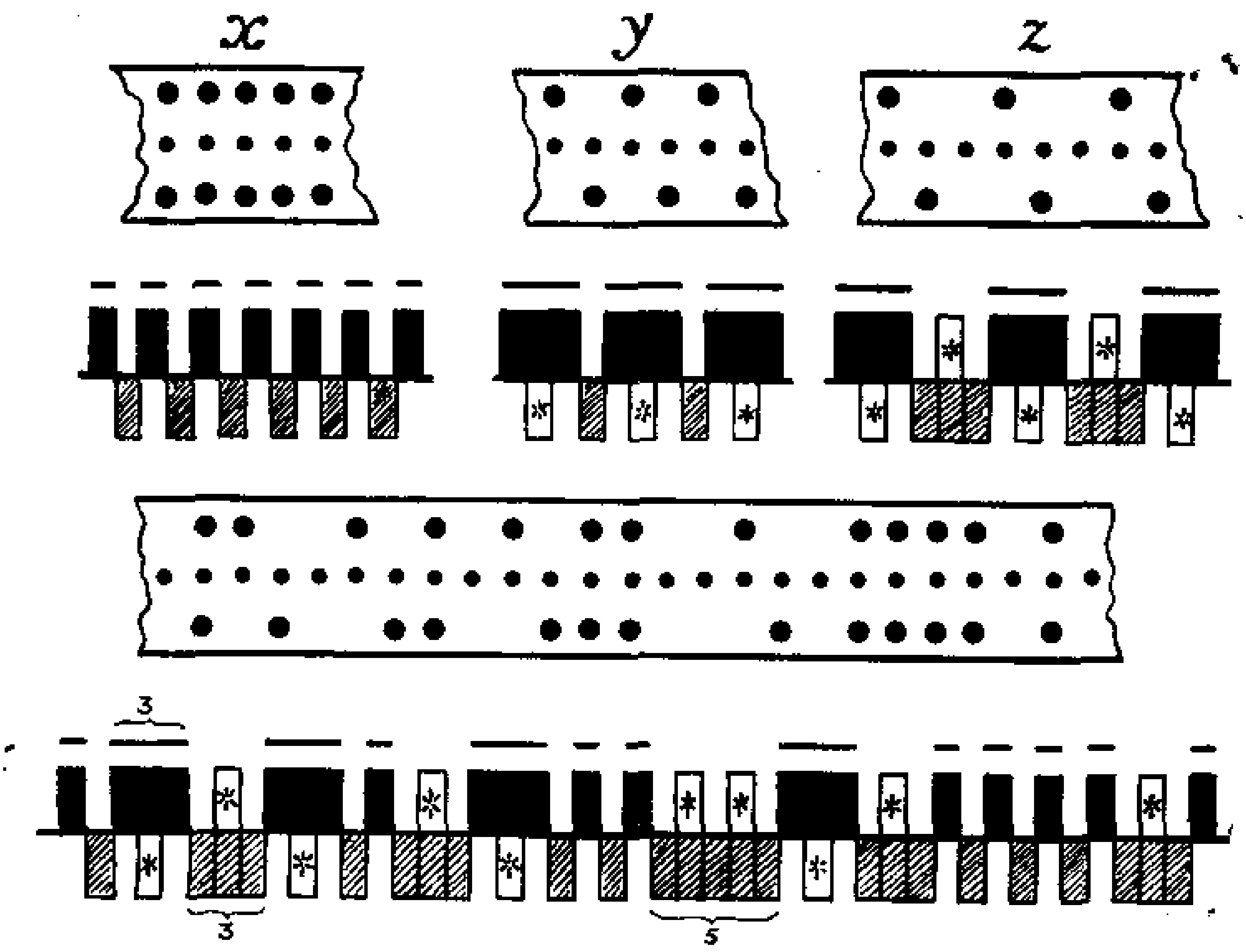


Fig. 84.

reversals is sent out. If at the end of the line a polarized relay were placed, having in its local circuit an inker, the latter would record a series of dots.

Now we will consider a slip on which is punched a series of dashes without intervening spaces, as at *y*, Fig. 84. The first upper hole allows M to pass through the slip and a marking current to be sent. When S rises, the paper blocks the way, so that the contact lever cannot be pushed over. The marking current, therefore, remains on. M again rises, but its way is likewise barred by the slip, so that it cannot complete its journey. Of course, the lever is already to marking, whither the full movement of M would carry it. When S again rises, the first lower hole allows it to pass through, and the current is reversed. Hence, whenever a reversal is thus missed, the marking current remains on for three times the normal interval.

When a single "space" separates the signals from each other on the punched slip, the spacing current is similarly lengthened. If, for instance, dashes and spaces alternate, as at *z* in Fig. 84, reversals are regularly missed, and marking and spacing currents of three times the normal or unit length (dot) regularly succeed each other. In the case of the double space separating the words, the spacing current is lengthened to five times the usual value. It will thus be easily seen how dots and dashes are combined to form letters and words. Fig. 84 illustrates the examples we have considered above. Wherever a reversal is starred it indicates that that reversal is missed, and the current previously put on the line remains on.

The transmitter shown in Fig. 82 is of the latest pattern, and it will be seen that the jockey-wheel and its spring are missing. In the place of these the two poles of a permanent magnet are brought, one on either side of the contact lever. The latter is thus prevented from retaining an intermediate position, and the arrangement is termed a "magnetic bias."

Receiver.—The latest form of Wheatstone receiver, weight-driven, is illustrated in Fig. 85. In its electrical arrangements it is very similar to the standard polarized relay of p. 41. Between the poles of two bar electro-magnets are two soft iron tongues or armatures, polarized by the proximity of a permanent horse-shoe magnet. The lower tongue is somewhat larger than the other, and carries platinum contacts, which, moving between two contact stops, form, with the latter, the local circuit. At the upper end of the spindle on which the tongues are fastened is a bent arm, carrying in a slot at its extremity one end of a light shaft. On this end is mounted a small disc, the marking disc. The other end of the shaft is connected by means of a flexible attachment with the clockwork of the instrument. The shaft is thus continually rotated, but the disc end has considerable freedom of movement. When the armatures move to marking, the arm carries over the end of the marking disc shaft, and brings the disc into contact with the slip, which is drawn rapidly past it. The marking disc revolves very close to, but quite independently of, another and larger revolving disc—the inking disc—a portion of which is beneath the surface of the ink. The marking disc takes up the ink from the inking one by capillary action, thus avoiding friction.

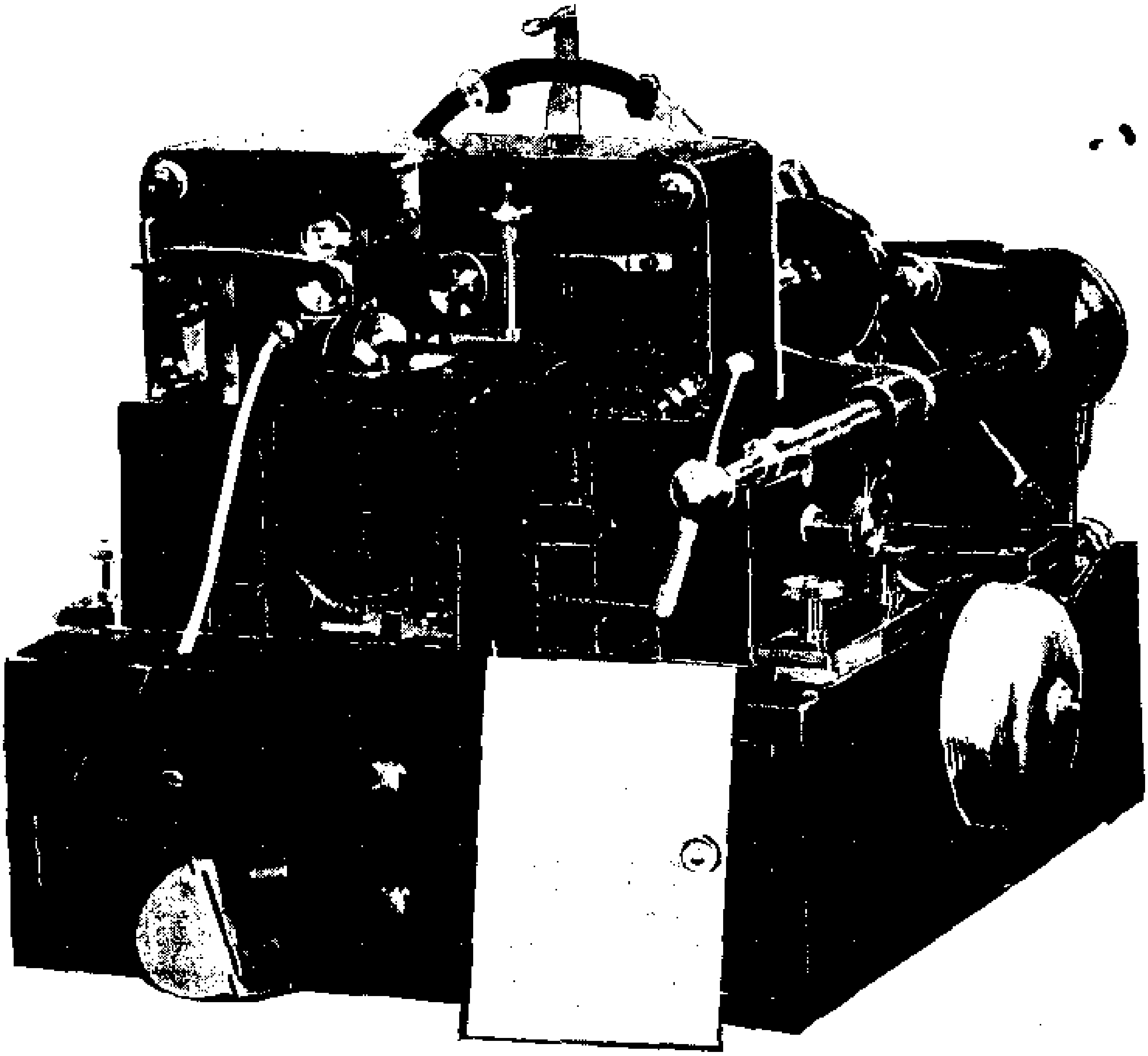


Fig. 85.—Wheatstone receiver.

It will be seen that the marking disc, and, therefore, the armatures, must always keep the same position with regard to the paper slip. The turning of the marking and spacing screw is therefore arranged to move the electro-magnets themselves instead of the contact points. The instrument is wound differentially: each coil, instead of consisting of a single length of wire, is formed of two half-lengths, and these are joined in parallel inside the instrument. Each length is of 200^{ω} resistance, so that each coil, measured from U to D or (U) to (D) gives 100^{ω}. With the straps connected for parallel, this, of course, becomes 50^{ω}, and, for series, 200^{ω}.

Shunted Condenser.—When the transmitter is running slowly, and without slip, the alternating currents sent out cause the armature of the distant receiver to vibrate. If the speed be increased the armature vibrates at a correspondingly higher rate. There is, however, a limit beyond which the receiver will be unable to follow the movements of the transmitter. The reasons are mechanical and electrical, but it is with the latter that we are now concerned. By making the moving parts as light as possible and carefully balancing them, and by the burnishing of opposing surfaces, we reduce mechanical inertia as far as possible. Electro-magnetic inertia or self-induction delays whatever effect we aim at. We complete a circuit containing a battery; self-induction immediately sets up an opposing E.M.F. which delays the rise of the current to its proper strength. Similarly, we break a circuit through which a current is flowing; immediately the E.M.F. of self-induction delays the disappearance of the signal. With an electro-magnet subject to a rapidly-alternating current, if the rate of the latter be increased to a certain degree, the electro-magnet becomes choked and the armature is unable to respond. To render high speeds attainable on automatic circuits a shunted condenser is applied, and we will now consider this.

In sending out a series of signals the best effect will be obtained if each signal is of the form shown at (*a*) in Fig. 86, where the dotted horizontal line represents time and height above this indicates strength of current. That is, on the application of the battery the current should rise immediately to its full strength, and on the withdrawal of the battery the current should be cut off sharp and clean. For the whole time that it lasts, such a signal is effective.

But the effects of self-induction, as we have seen, are to delay the rise of the current to its proper value when the battery is applied, and to cause a heavy rush of current in the same direction when the battery is withdrawn. The shape of the signal thus distorted is shown at (*b*) in Fig. 86. These alterations in its shape are important. At the commencement of the signal the receiving instrument will not be actuated until the current has risen to the required value. The time thus occupied

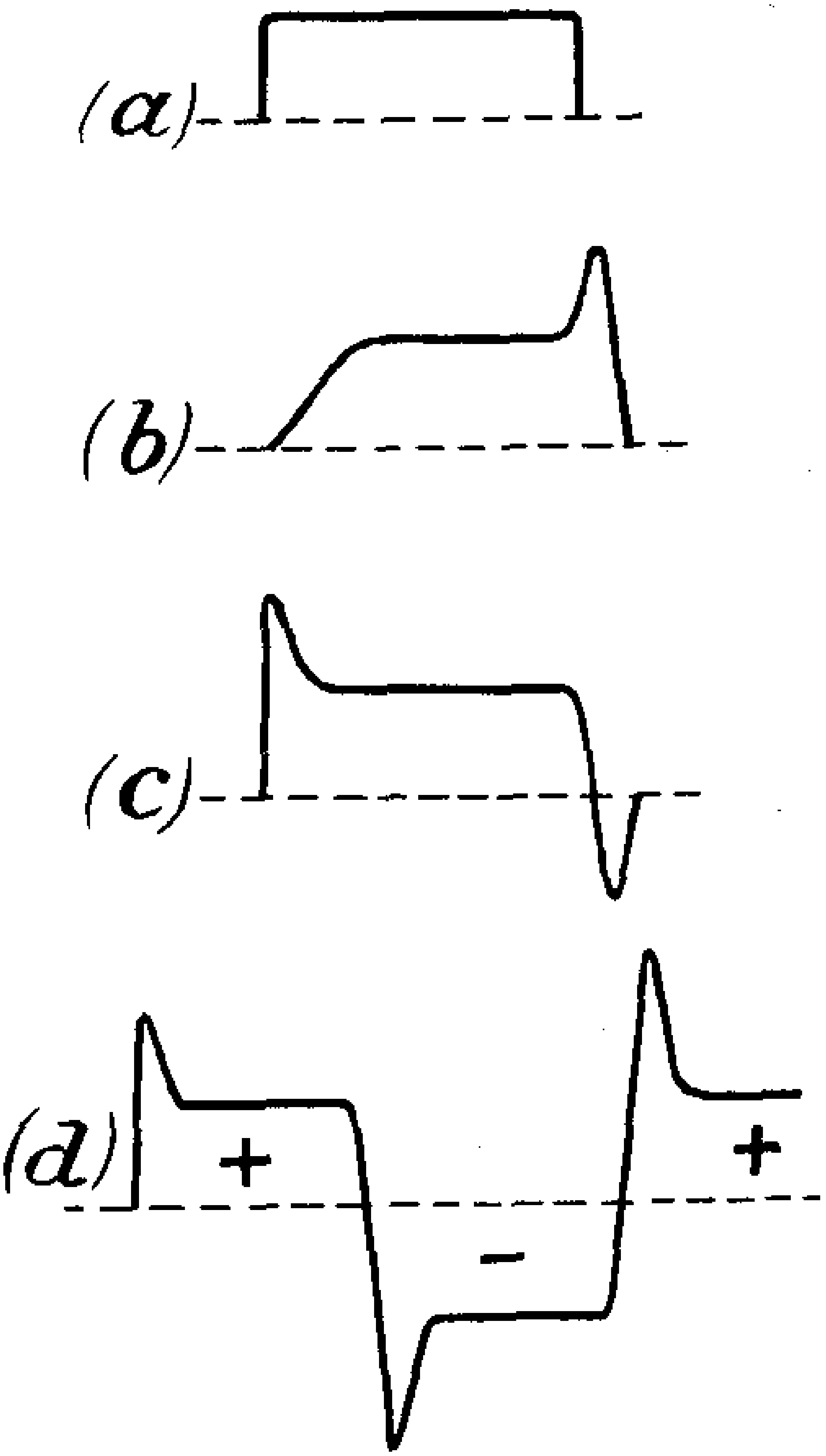


Fig. 86.

in rising is clearly lost, for it shortens the duration of the signal. In hand-working the length of this period compared with the length of the signal itself (even a dot) is negligible, but at high automatic speeds it becomes very important. The accession of strength at the end of the signal, too, is bad, as it is then desirable that the current should disappear as quickly as possible. To counteract this evil effect at the end of a signal is the object of the high resistance shunt on the sounder. The electrical energy thus suddenly released then discharges itself through the resistance. Otherwise it would spark across the separating contacts of the relay. We may remark here that nearly all devices against self-induction are directed against it at the termination of the signal, in order to prevent the resulting sparking.

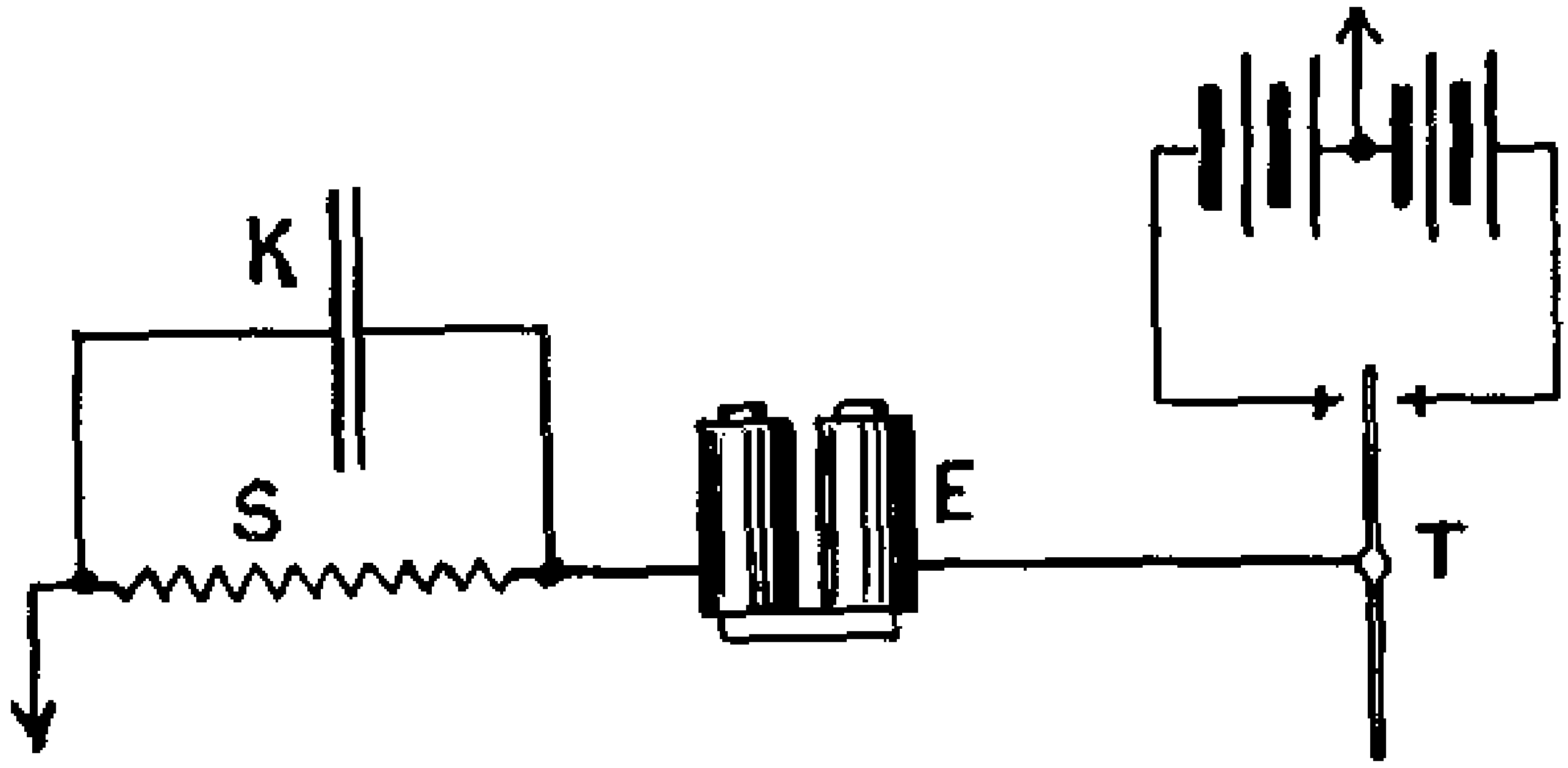


Fig. 87.—Shunted condenser.

Now instead of containing inductance, let us imagine that our circuit contains a condenser across which is placed a resistance coil of fairly high value, the rest of the circuit having practically no resistance. On the depression of the key there is a heavy rush of current to the condenser, and until the capacity of the latter is satisfied, no current will pass through the shunt. When the condenser is fully charged a current is established in the shunt, but its value is much less than that of the initial current charging the condenser. On the release of the key, discharge takes place. In this case, as the resistance of the circuit is low, the whole of the discharge takes that path. If however, as would occur in a practical case, the circuit has a considerable resistance the discharge will divide between the shunt and the rest of the circuit. Whatever takes the latter path is in the reverse direction to the signal. This results in the form shown at (*c*) in Fig. 86.

On comparing (*c*) with (*b*) in this figure it will be seen that if we can combine them they will produce a well-shaped signal, rising quickly at the commencement and being cut off clean at the end.

To do this is the function of the shunted condenser; or rather the electro-magnet having distorted the signals, we insert the condenser to correct them. It is placed as shown in Fig. 87, where K is the condenser, S the shunt, E the electro-magnet of the receiver, and T the contact lever of the transmitter at the sending end of the line.

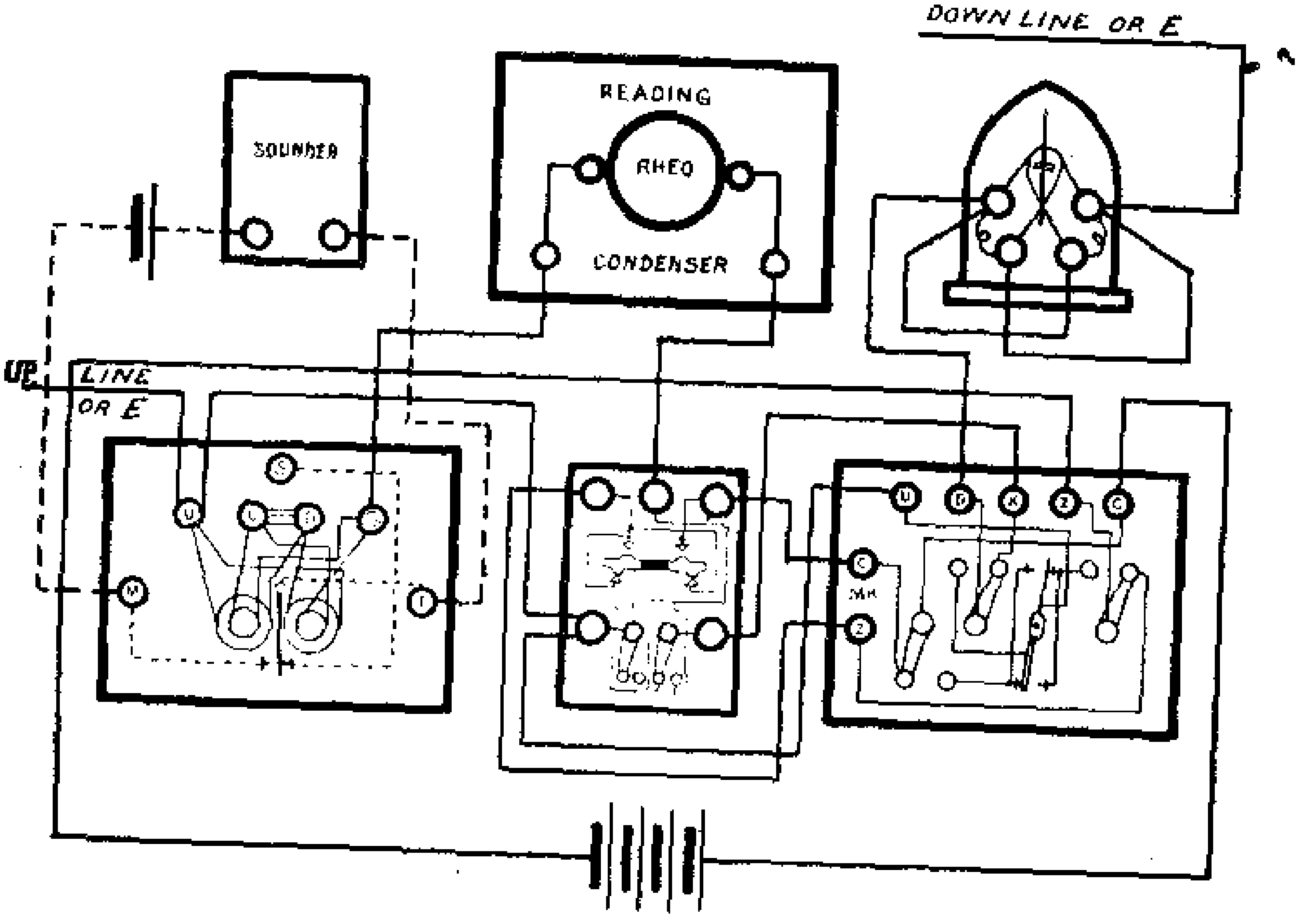


Fig. 88.—*Automatic: primaries.*

When the transmitter lever moves to the right the battery is applied. A heavy rush occurs at the moment of making contact, thus drowning the "backing" effect of the electro-magnet. When the lever quits the right-hand contact the circuit is disconnected until it reaches the left-hand one. If the interval of disconnection were at all prolonged, the condenser discharge would all pass through the shunt. But on quitting one contact the lever passes swiftly to the other, thus putting on a reverse current.

If anything is left in the condenser when this new contact is made, the discharge is in the *same* direction as the new current and thus further assists its rapid rise. This is shown graphically at (*d*), Fig. 86. Under these conditions the discharge (or that portion which does not pass through the shunt) from the condenser at the end of the old signal is added to the effect of the charge at the commencement of the new. The antidote to self-induction is thus applied to the *beginning* of the signal.

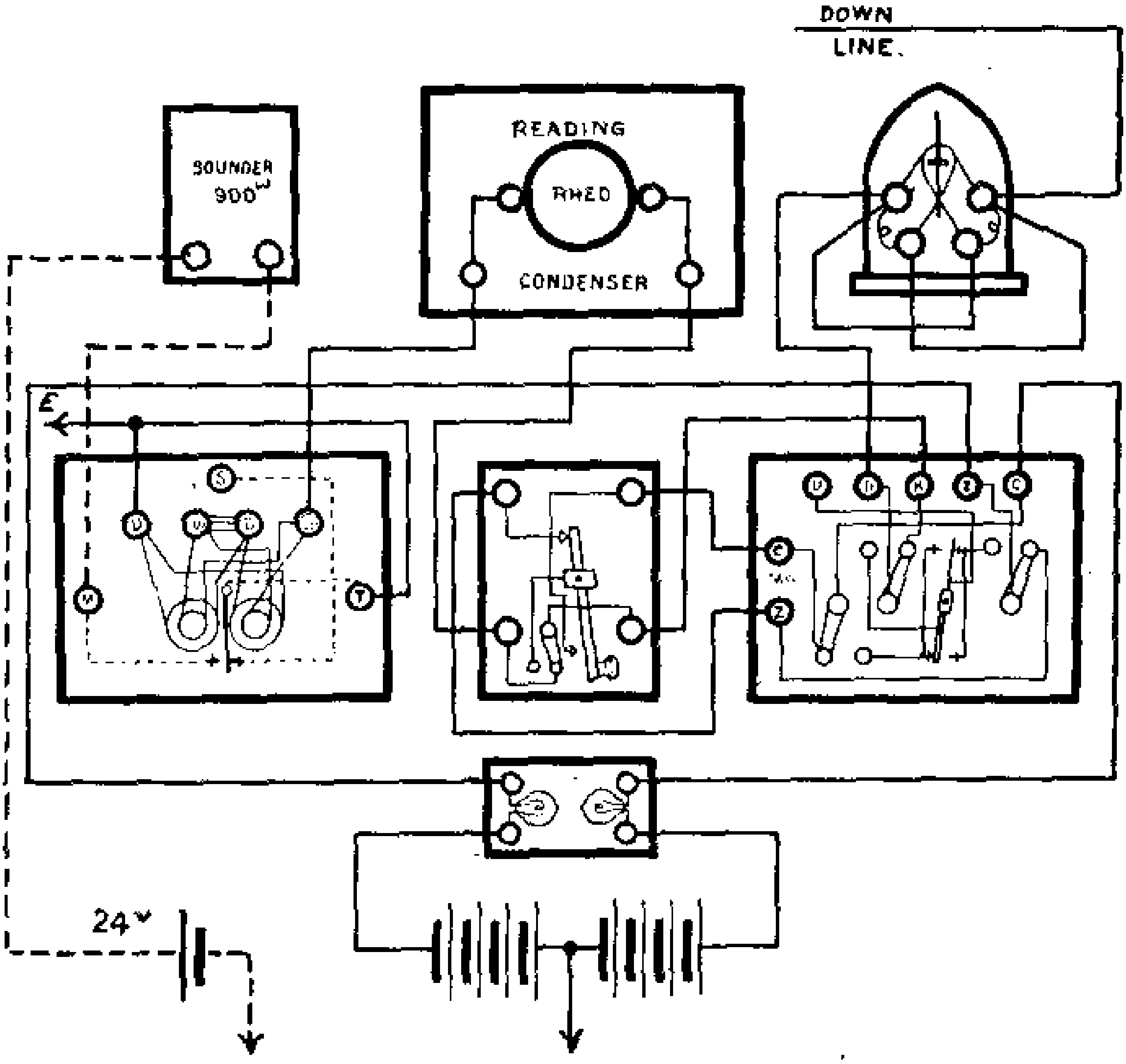


Fig. 89.—Automatic: secondaries.

Creed Receiving Perforator.—This is an ingenious piece of mechanism by which the currents from a Wheatstone transmitter, when received at a distant station, instead of being recorded in dots and dashes by the receiver, cause a white slip to be punched so as to form an exact replica of the perforated slip passing through the sending transmitter. The received slip, previously centre-holed, is drawn continuously past a pair of punches at the same rate as the sending slip. One of these punches is for making the spacing, and the other the marking perforations. The spacing and marking currents from the line pass through the coils of a polarized relay, the movements of whose tongue, by means of another electro-magnetic system, cause a small valve to admit compressed air to one side or the other of a piston working in a cylinder. The movement, in one direction, of this piston, strikes forward the spacing punch whilst the reverse movement actuates the marking punch. The slip, thus perforated, is ready for fresh transmission by passing through one or more transmitters at the receiving office.

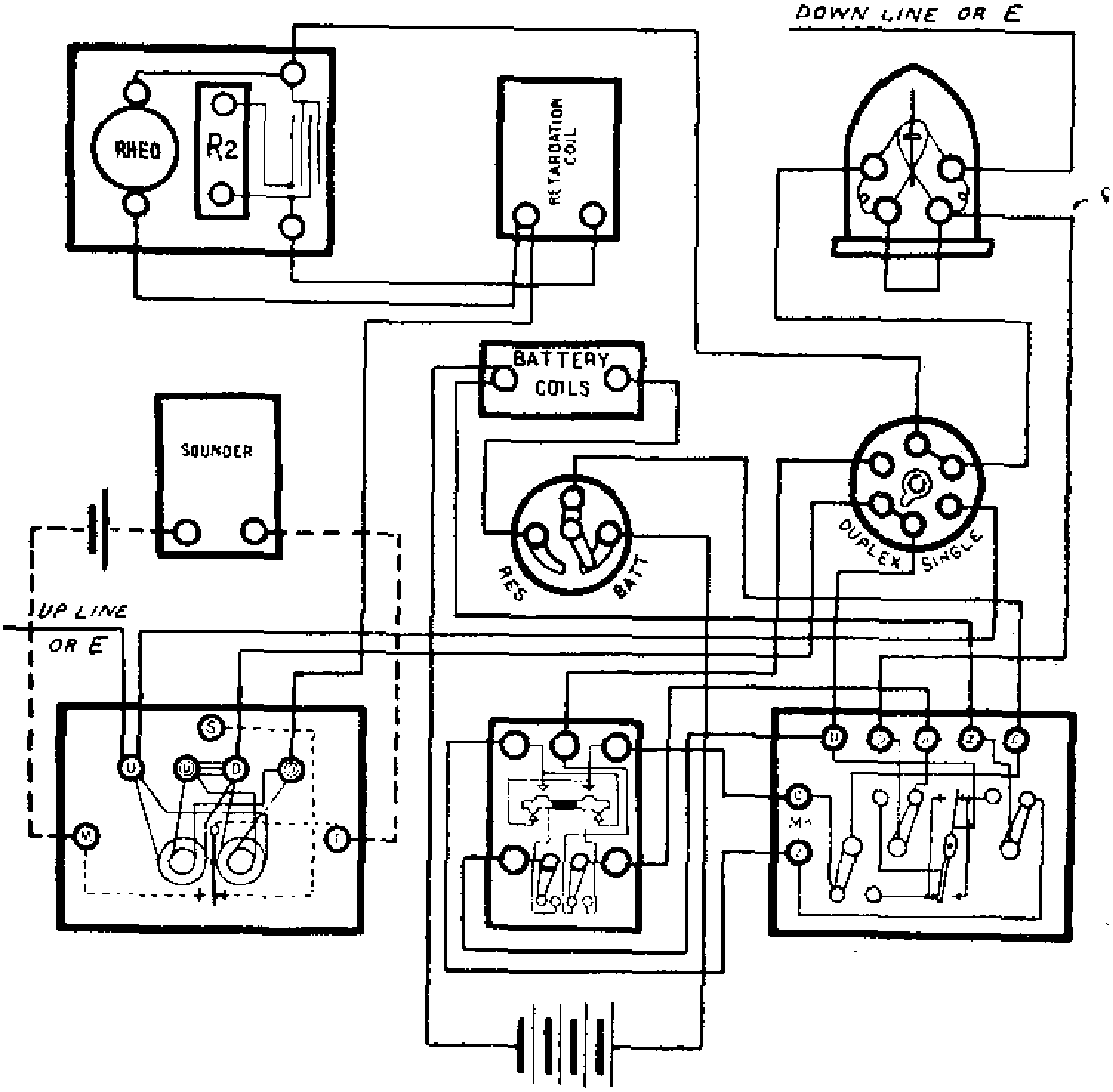


Fig. 90.—Automatic, duplex or single, primaries.

The Murray-Creed Receiver or Printer automatically transcribes from the Wheatstone perforated slip. That is, an item of news punched on the ordinary white slip is run through the printer, and thus translated into type-written characters ready for delivery. An office equipped with this and with the Creed receiving perforator can thus run the received perforated slip through the transmitter to distant offices, and then through the printer for delivery in its own town.

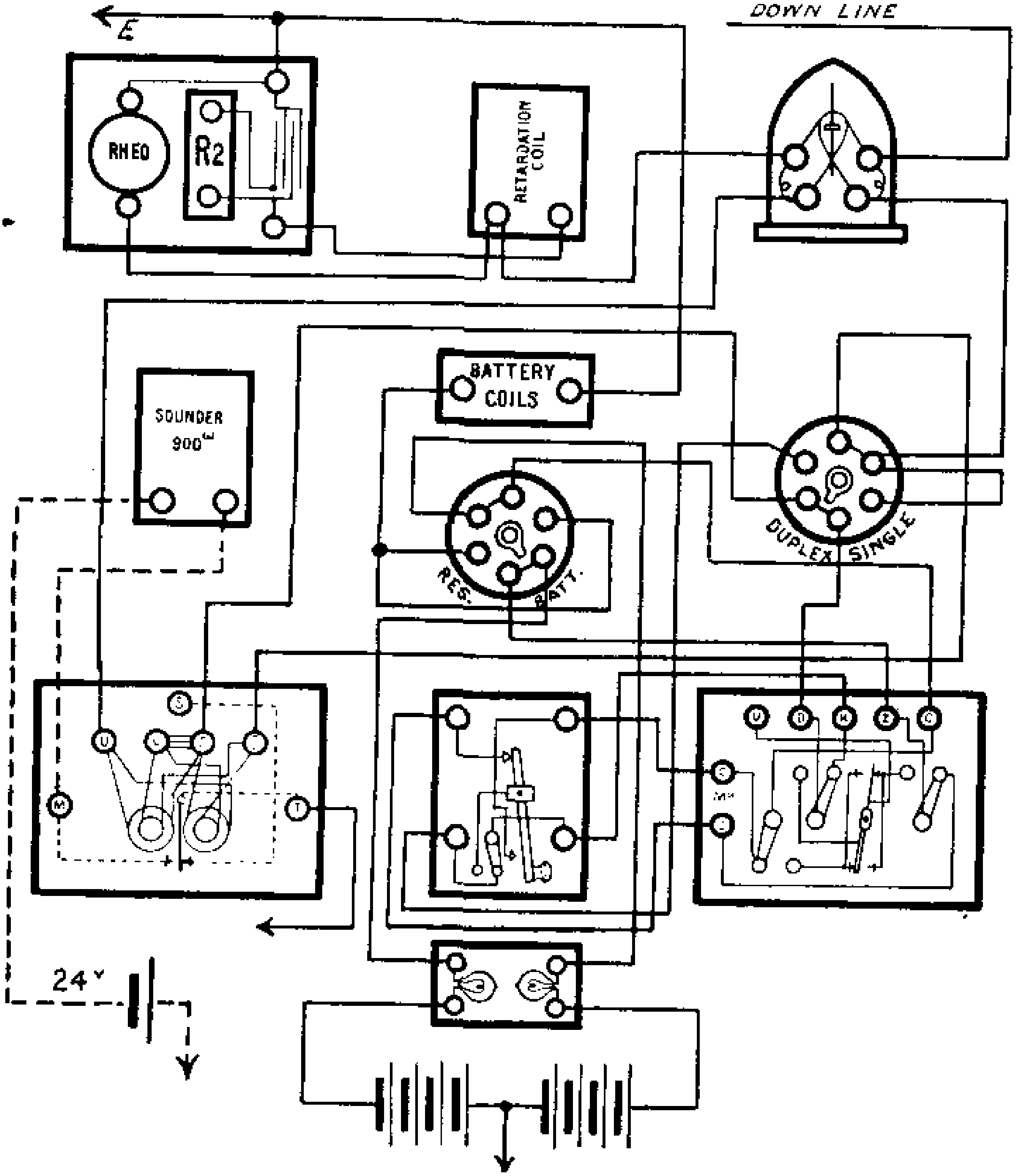


Fig. 91.—Automatic, duplex or single, secondaries.

Automatic Set.—Fig. 88 gives the connections of a complete set of automatic apparatus for sending and receiving. In the base of the transmitter is a triple switch, actuated by the same lever as that which starts and stops the clockwork. In its position of rest, as shown, the batteries are joined through the transmitter to the key, and the terminal K connected to the right-hand front terminal of key. When the instrument is running the key is cut off, and the battery is applied to the circuit by way of terminals D and U.

For secondary batteries the connections are as shown in

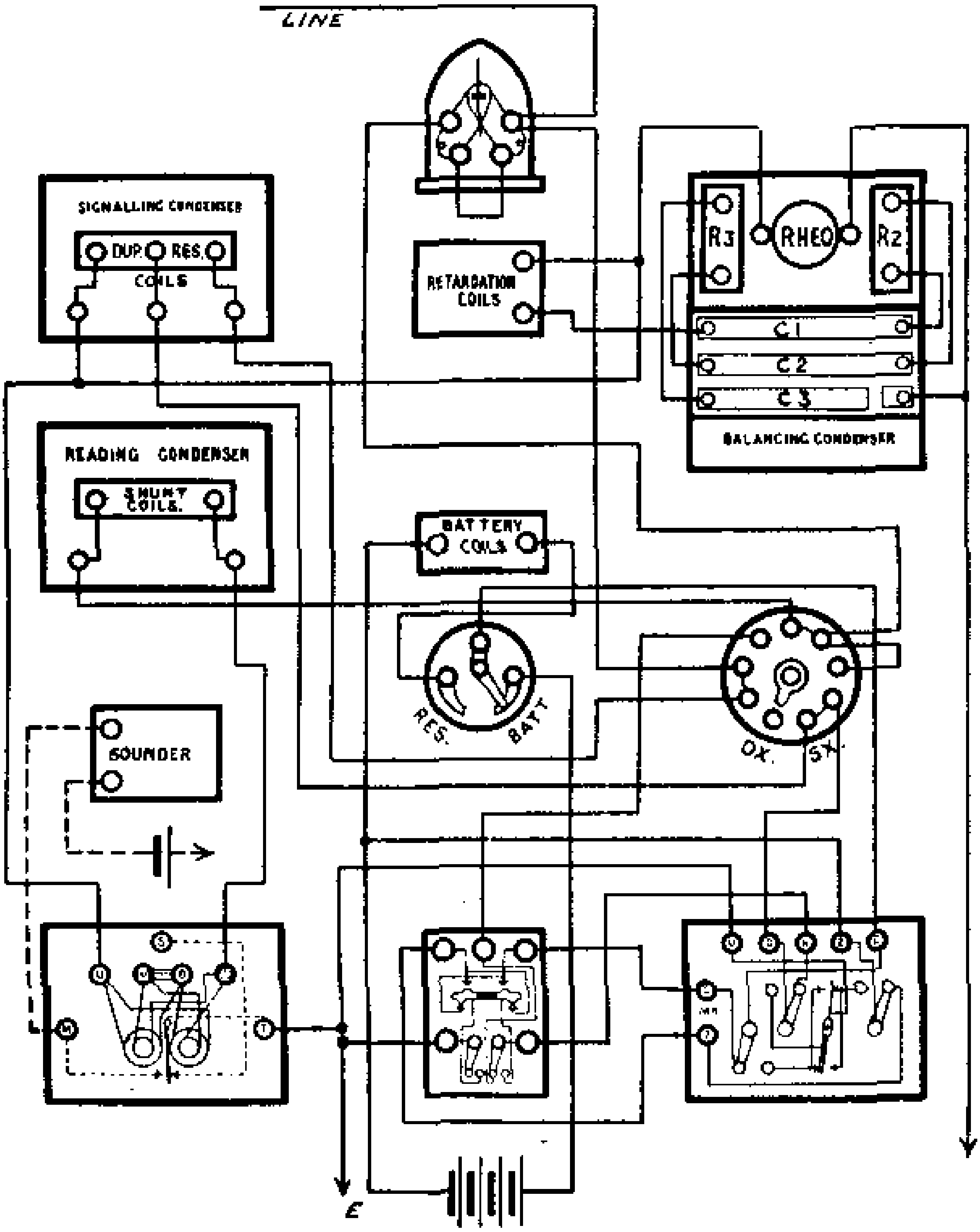


Fig. 92.—Automatic: bridge duplex or single, primaries.

Fig. 89 (up office). The ordinary double-current key is replaced by a single-current one with switch. The upper contacts of the transmitter lever and the terminal U are necessarily thrown out of use. At a down office the receiver connections must be reversed, the battery wires on the transmitter and the connections on the upper terminals of the galvanometer.

Duplexing.—This is generally done on the differential plan, as shown in Fig. 90. The connections for secondary batteries at an up station are given in Fig. 91. For a down station the following reversals are required :—

Battery wires on transmitter.
Connections on (D) and U of receiver.
Connections on upper terminals of galvanometer.
Connections on lower terminals of galvanometer.

Fig. 92 gives the connections for automatic duplex or single on the bridge system, using primary batteries.

The great advantage of the automatic system is that it utilises to the full the electrical possibilities of the line, or gets the maximum amount of signals through it. But the sending and receipt (writing-down) are no longer simultaneous. A message, after being punched (the equivalent of "sending" on a key), awaits its turn for passing through the transmitter. On its receipt at the receiving station it awaits its turn in writing up. A waiting "slip" has not the insistence of a calling station. Hence Wheatstone is never resorted to for commercial work unless it is absolutely necessary, as it generally spells delay. For press work, on the other hand, for special events and breakdowns, where the circuit accommodation is temporarily insufficient for the traffic, it is unrivalled.

CHAPTER VI.

MULTIPLEX TELEGRAPHY.

We have now to consider quite a different principle for increasing the carrying capacity of a wire. The drawback to automatic working is that the sending and receipt (writing down) are not simultaneous, but an interval, more or less prolonged, separates the operations. The multiplex system retains the advantages of hand signalling and simultaneous reception, and also utilises the property of more rapid signalling possessed by the line.

The principle is as follows:—The line, instead of being permanently connected to the apparatus, makes a regularly-recurring contact with it, as in Fig. 93. At each station, X and Y, the line is brought to a movable arm which is constantly revolving. This arm carries a metallic brush which sweeps over a metal circle divided into, say, four insulated segments, *a*, *b*, *c*, and *d*. If the brushes or "trailers" run in synchronism, then *a* at X will be connected to segment *a* at Y for a quarter of a revolution, and similarly *b* with *b*, &c. By "synchronism" is meant not only that the two trailers run at exactly the same speed, but that the brush at X is on segment *a*, whilst that at Y is also on *a*. By this means only *a* and *a*, *b* and *b*, &c., are connected together. Assuming that the current occupies no time in passing, the effect, under these conditions, of the permanent

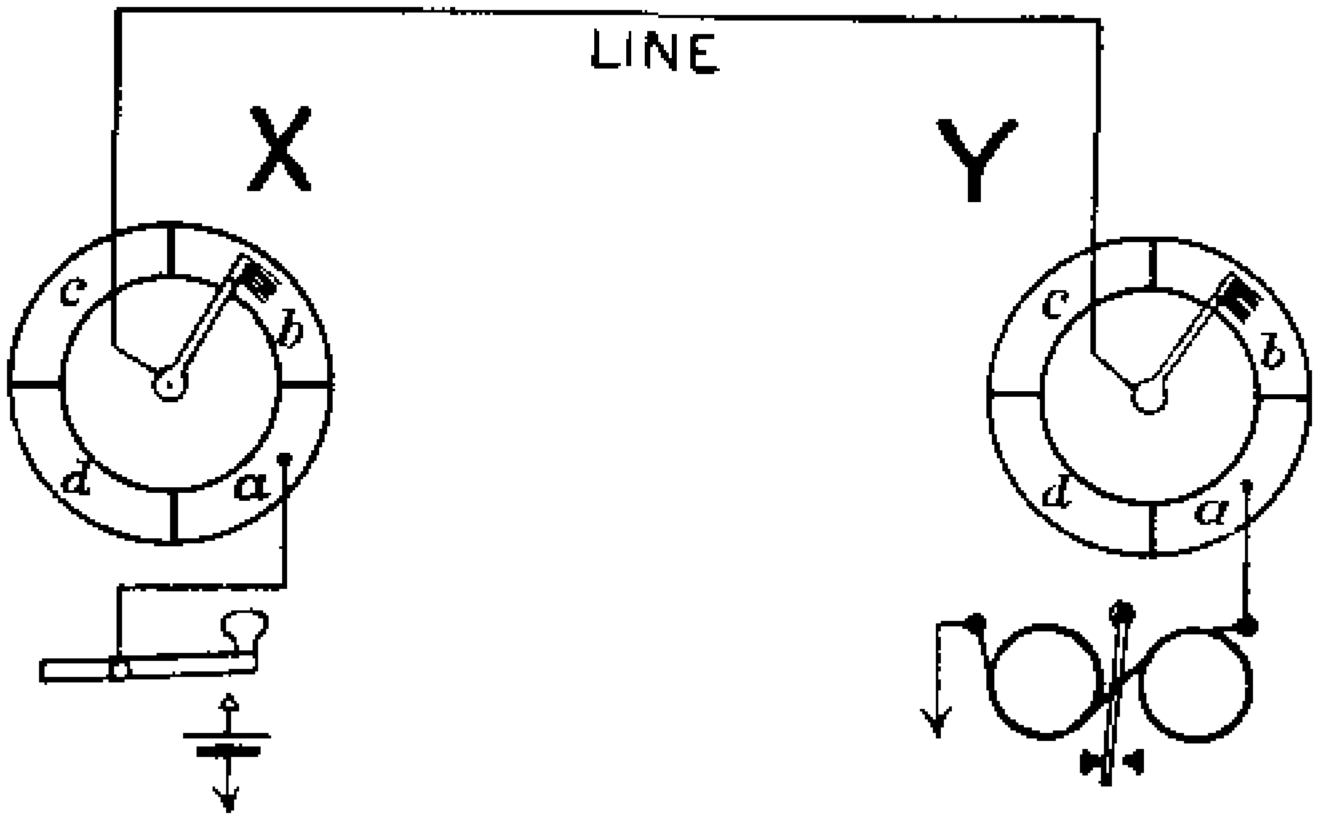


Fig. 93.—Multiplex principle.

depression of X key is that the relay at Y receives a current of certain duration, followed by a break three times as long for every revolution of the trailer. Suppose that the duration of this contact between trailer and segment is about equivalent to the length of a "dot." Then if a dot be sent whilst the brushes pass over *a*, it will be received intact on the relay. But if the depression of the key commences just as the trailers are leaving or after they have left *a*, the signal will be clipped or lost. A "dash" will inevitably be cut short.

Instead, however, of running the trailers at this rate, we can run them at a very high speed, say several hundred revolutions per second. Under these changed conditions, when the key is depressed, even for a dot, the duration of the contact is sufficient to allow the trailer to make a number of revolutions and a rapid succession of impulses to be sent to line. A dash simply means a longer contact and greater number of revolutions of the brush and a longer-continued stream of impulses passes to line.

At the receiving end the relay used has larger cores, a higher resistance and much greater self-induction than the ordinary relay. A condenser of 10 mfds. is also placed across its terminals. The rapidly-succeeding impulses passing through its coils are converted into continuous signals on the sounder. When an impulse is received the tongue moves to marking, and the condenser is charged. As soon as the impulse dies away the condenser discharges through the relay. The discharge and the extra current from the coils are in the same direction through the instrument as the impulse itself and the tongue is thus kept over whilst the shower lasts. In double-current working each shower of "marking" currents is succeeded by one of "spacing" currents.

Before the introduction of this relay, a plain electro-magnet was used. This had no yoke, and beneath its cores was a permanent magnet. The cores were thus polarized, and thus constantly attracted the soft-iron armature. The latter was normally held off the cores by a spring. The impulses of current passed through this polarized electro-magnet in such a direction as to reinforce the existing polarity, and the armature was thus drawn down. A condenser was also used, and the effect of the permanent polarity and the discharge of the condenser was to keep the armature continuously down whilst the shower of impulses lasted.

It will be seen that the apparatus is worked just as if it had entire possession of the line. It is, however, actually disconnected from the latter for three-quarters of each revolution of the trailers. If, therefore, we provide the other three segments with sets of apparatus, they will be able to work in just the same way as the first set, and we shall have four independent channels or "arms" working on the same wire.

If the metallic circle of Fig. 93 were divided into three, five, or any other number of segments we should have a corresponding number of arms, but the greater the number the shorter the duration of the contacts. Six is the maximum in practice, and this is possible only on lines of a certain length. On longer circuits a lesser number is practicable.

The likeness of the two-arm arrangement to duplex and of the four-arm to quadruplex is apparent, and a distinguishing nomenclature is adopted. Thus two, three, four, five and six-way multiplex are termed diode, triode, tetrode, penthode and hexode working respectively. The difference also between the methods will be easily seen. Each arm of the multiplex can be worked up or down indifferently, if therefore X has a glut of work and Y none, all arms can be utilised in one direction. In duplex and quadruplex the direction of the channels cannot be varied.

Synchronism and Isochronism.—The great condition of success is that the two distributors shall move in synchronism with each other. By this, as we have said, is meant not only that the speeds of the two trailers are the same, but that both are on similar segments at the same time. If they moved at the same rate, but the trailer at X were on segment 1, whilst that at Y were on any segment other than 1, they would be moving in "isochronism." The latter term involves identity of speed; "synchronism" implies identity of speed and phase. No better illustration of this is needed than that of two clocks, both keeping exact time. If one indicates Greenwich and the other New York time, they are moving isochronously. If both indicate New York or both Greenwich time, they are moving synchronously.

Distributor.—This includes the segments, trailer, and brush, and the necessary motor. It is so arranged that any number of arms up to a maximum of six can be worked. The segments are only a portion of the circle. They are repeated again and again, so that the trailer goes through the series many times during a single revolution. By this arrangement the trailer runs at a lower speed, but yet makes the contacts of the same duration. All the No. 1 segments are brought to a terminal, all the No. 2 to another, and so on. Further, the series, instead of consisting of six segments (hexode), consists of twelve. For hexode, then, each arm has two segments, the first being connected to the key for sending, and the second to the relay for receiving. This is indicated in Fig. 95. The rate of movement of the trailer is such that it occupies about $\frac{1}{500}$ second in passing over each segment.

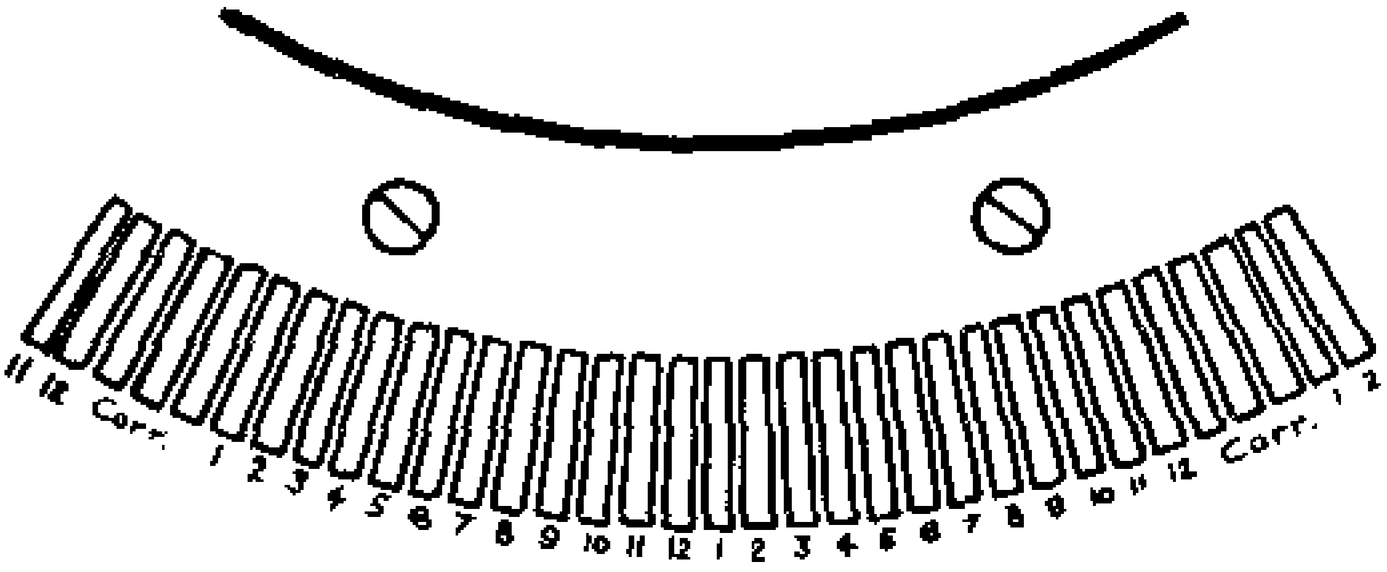

11 12 Corr. 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 Corr. 1 2

Fig. 94.

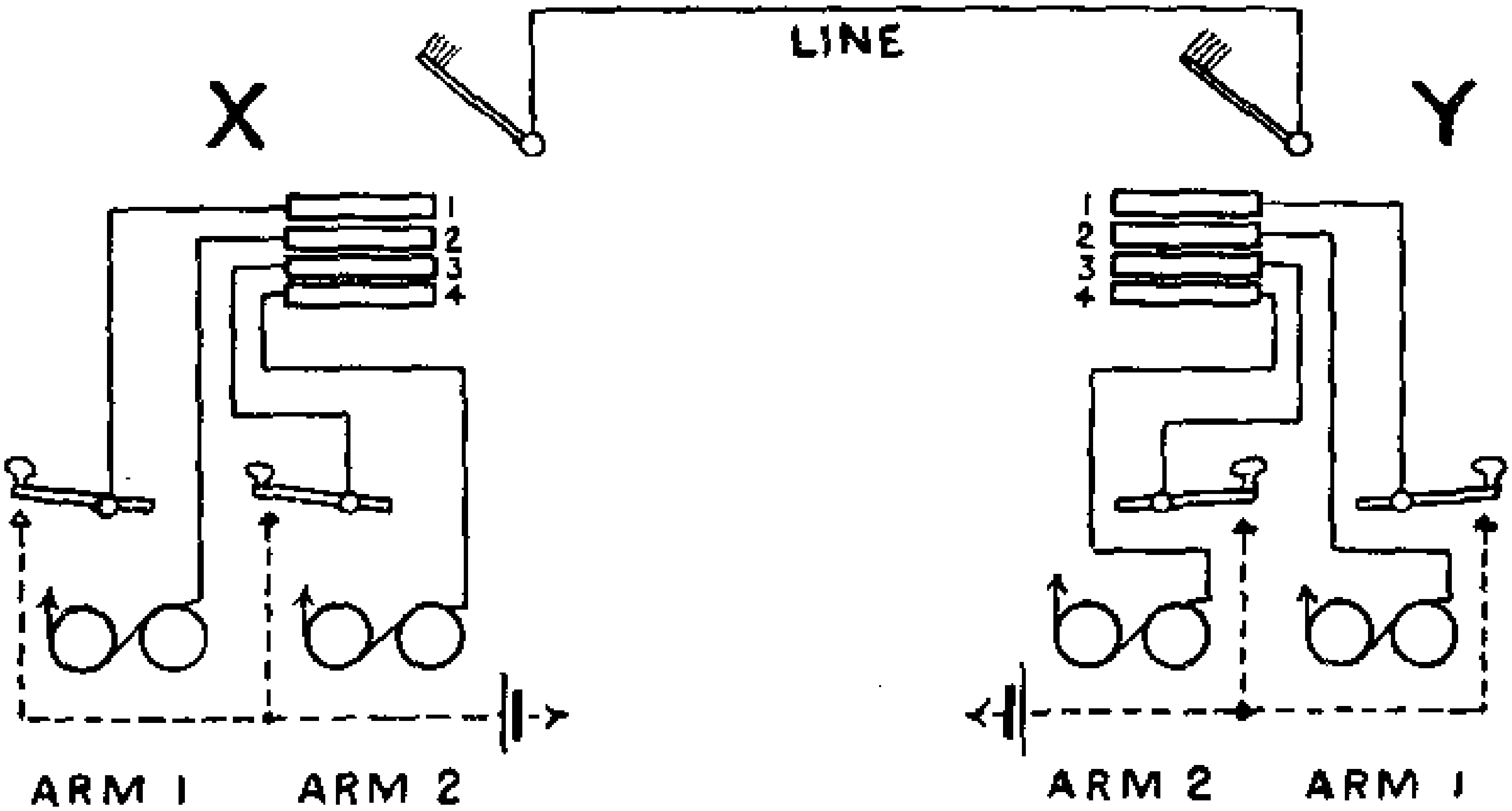


Fig. 95.

Motor and Reed.—To obtain a motion as nearly uniform as possible the distributor is driven by a small synchronous motor. By a synchronous motor is generally understood an electric motor fed by alternating currents at a certain periodicity. Such a machine runs in synchronism with the pulsations of the driving current, and these, being constant, the speed of the motor is constant also—that is, if it be overloaded it will not slow down, but will stop. The motor employed is La Cour's "phonic wheel," shown diagrammatically in the upper part of Fig. 96. A soft iron wheel, with (in this case) fifteen teeth, rotates on a vertical axle, which also carries the trailer. An electro-magnet, placed as shown, keeps this wheel in constant rotation. The reed is a simple bar of steel, firmly fixed at one end and free at the other. On the free end is mounted a movable weight, by which the rate of vibration is (approximately) adjusted. On one side of the reed is an electro-magnet, as can also be seen from Fig. 96, and, on the other, a contact, thus constituting a "make and break"

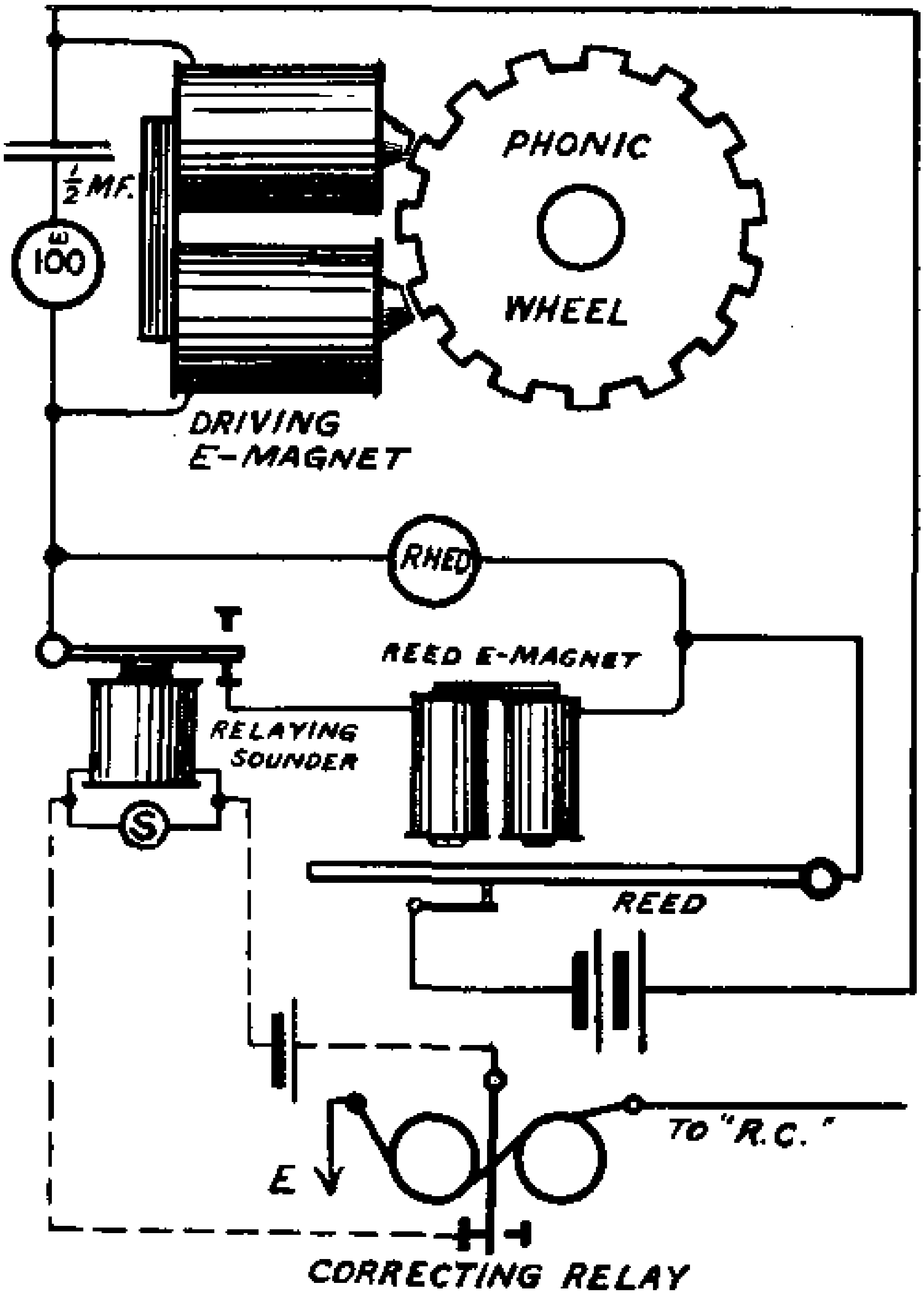


Fig. 96.

arrangement, by which the otherwise continuous current from the reed and motor-driving battery is broken up into impulses, all of which are in the same direction. The reed is thus kept in motion, and the intermittent currents pass through the coils of the motor magnet, propelling the wheel forward a tooth at a time in synchronism with the pulsations. As the motor runs in exact obedience to the pulsations of the driving current, these latter must be sent at a constant rate. This is the office of the reed—to maintain a perfectly steady, uniform speed of vibration. Further, the two reeds at the two stations are adjusted to the same rate of vibration, the necessary fineness of adjustment being obtained by means of the rheostat across the coils of the electro-magnet, as seen in Fig. 96.

Correcting Currents.—We have, then, two reeds, vibrating at exactly the same rate, and thus rotating the phonic wheels, and, by them, the trailers, at the same speed. But, in practice, variations inevitably occur. Connecting currents are therefore regularly exchanged between the two stations, certain segments (Fig. 94) being set apart for this. That is, when station X sends a correcting current, a segment at Y is available for its receipt, and *vice versâ*. If the reed at either station is vibrating at the normal rate the correcting current passes direct to earth. If the reed be lagging slightly the correcting current passes through the correcting relay shown in Fig. 96. The tongue of this relay normally closes the circuit of a relaying sounder whose armature completes the circuit of the reed magnet coils. The reed has its own natural rate of vibration (all adjustments being made), but the effect of the driving currents is to lower this slightly. When the correcting relay is actuated the armature of the relaying sounder rises, and breaks the circuit of the reed magnet. The driving currents are thus cut off from the reed, but not from the motor. The reed is thus left to itself, and vibrates more quickly. The pulsations are, therefore, sent through the motor magnet at a more rapid rate, and the motor is accelerated. The interval during which the currents are cut off from the reed is, of course, very short, not long enough to allow the reed to come to rest. The correcting currents thus always act in the direction of accelerating the slower distributor.

In the earlier arrangement of the reed the correcting currents had the opposite effect, of retarding the vibration. The free end of the reed moved between the poles of an additional electro magnet. Normally, the latter was not energised, but when a correcting current was received on the correcting relay this electro-magnet was actuated, and thus retarded the movement of the reed.

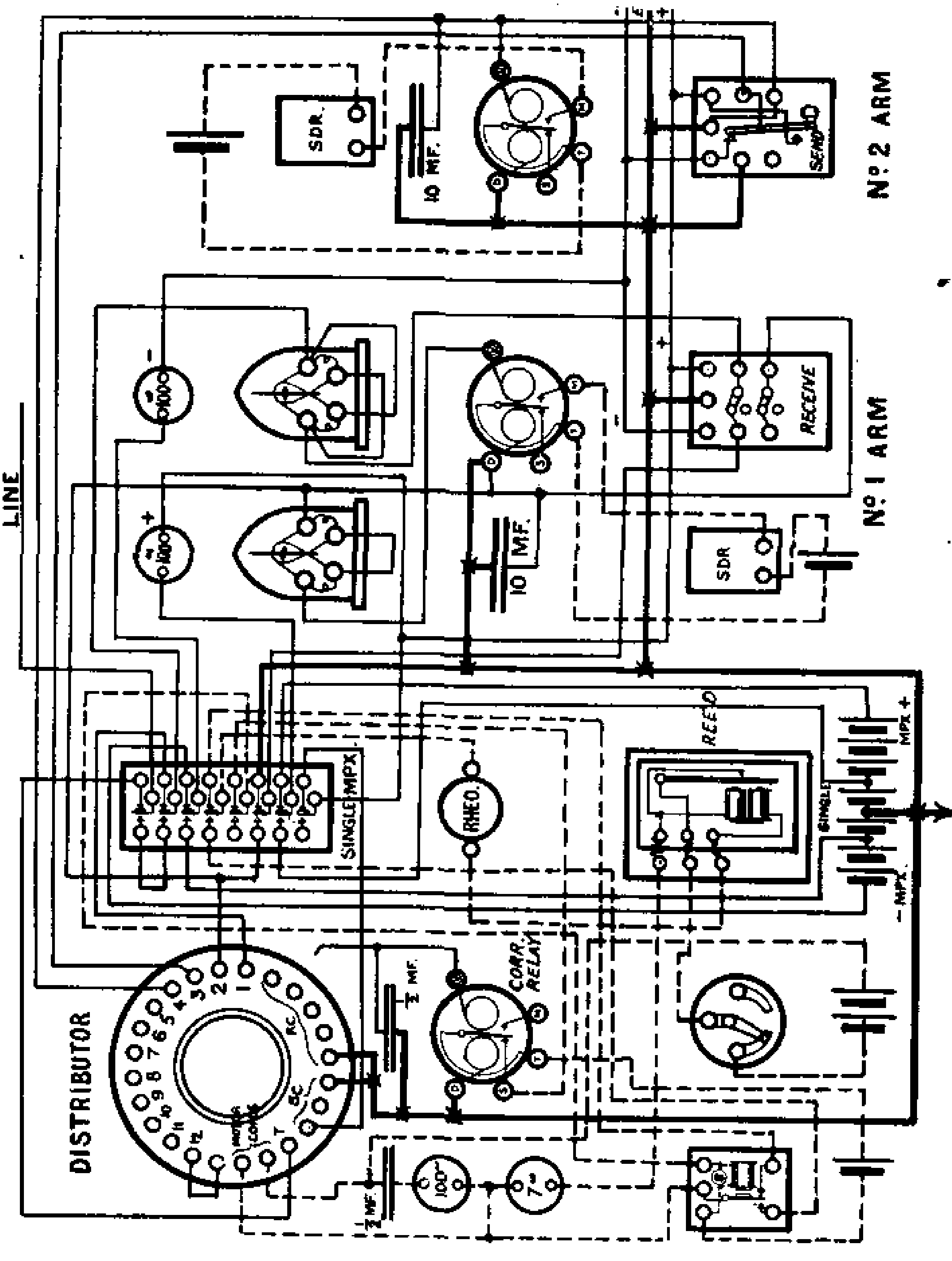


Fig. 97.—Multiplex—hexode working.

Now, if, as we have assumed, the current occupies no time in passing from office to office, an impulse sent from segment 1 will be received on segment 1; but this condition does not obtain. The current passes with enormous rapidity, but some time, however short, is necessarily occupied. Further, with impulses following each other so rapidly, the time occupied in transit becomes relatively considerable. Assume that on a certain circuit this time is $\frac{1}{360}$ second, the same period as the duration of each contact. An impulse sent from segment 1 will reach the other office when the brush there is on segment 2, which is connected to the relay of the first arm. We are, of course, arguing backwards, for the fact that the time of transit is of the value assumed renders hexode working practicable. If the passage of a signal requires double this time an impulse sent on segment 1 will be received on segment 3, which would have to be connected to the relay. Three segments being thus required for each arm, only tetrode will be possible. If the time be greater still, four segments may be required, and only triode working practicable. The number of arms workable thus depends (amongst other considerations into which we will not enter) on the time of transit or on the amount of *retardation.*

This is conveniently expressed as so many segments retardation. Thus, with one segment retardation, hexode is practicable; two segments, tetrode, and so on. The diagram of connections is given in Fig. 97. Arm No. 1 is shown receiving, arm No. 2 sending. Succeeding arms are joined up precisely as No. 2. The 8-bar switch is to enable the circuit to be worked simplex at will.

Duplex Multiplex.—We have seen that the number of arms workable on a certain line depends, amongst other conditions, on the retardation. That the latter should thus limit the number is due to the necessity for up and down working, and for the exchange of correcting currents. Ignoring the latter for the moment, and assuming that only working segments have to be dealt with, it will be seen from Fig. 98 that, if we work the circuit in one direction only, full hexode will at once be practicable, however great the retardation may be. (This is on the assumption that the retardation is the only limiting factor.) At *a* and *b* in Fig. 98 the line has a retardation of two segments. Working up and down, a signal sent by X on segment 1 will be received at Y on segment 3, as indicated at *a* by the black band passing between them. Likewise, a signal sent on 1 at Y will reach X on 3, as shown by the dotted band. Three segments are thus required for each arm, giving tetrode as the limit. But let us work X to Y *only*, on all arms, as at *b*. The signals sent on 1 will be received on 3, as before. As Y, however, does not now send at all, it is not necessary to reserve segment 3 at X for reception. X's second arm may therefore be joined to this. X will thus send on segments 1, 3, 5, 7, 9, and 11, the signals from segment 11 being received on No. 1 of a fresh series at Y. This enables us to work full hexode.

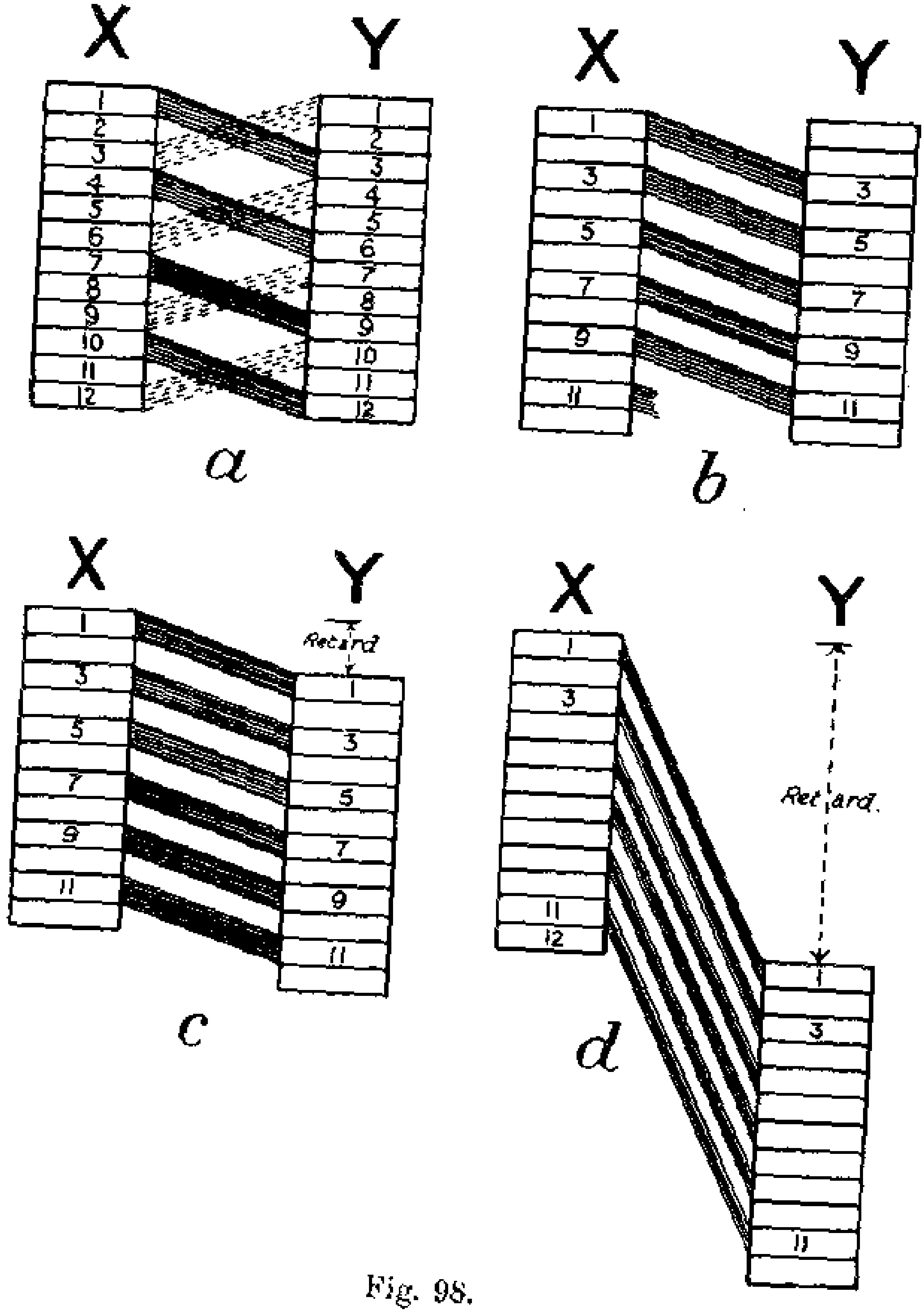


Fig. 98.

Again, as Y never requires to send, there is no necessity to run the distributors synchronously. The relays of all the arms at Y can be joined to their proper segments (1 or 2), and the receiving distributor run behind the sender, as at *c*, Fig. 98, by an amount equal to the retardation. Also, if the latter be

12 segments, or a complete series, the state of affairs will be undistinguishable from a circuit having *no* retardation, as shown at *d* in the same figure.

The conditions assumed above are impracticable for single working, but if we apply the duplex principle they are just the conditions that would obtain. Fig. 99 gives the theoretical connections of a duplexed (bridge) multiplex circuit. The difference between this and the ordinary bridge duplex circuit consists in the fact that the apex of the bridge, instead of being permanently connected to one key, is to be joined successively to the sending keys of all the arms, and the "bridge," instead of permanently including one relay, is to include successively the relays of all the arms. We need then four distributor plates, two for sending and two for receiving. The sending plate at one station and the receiving plate at the other must move in *isochronism*, the latter being behind the former by a distance equivalent to the retardation of the line. If this be exactly a cycle, however, synchronism will, for all practical purposes, be established.

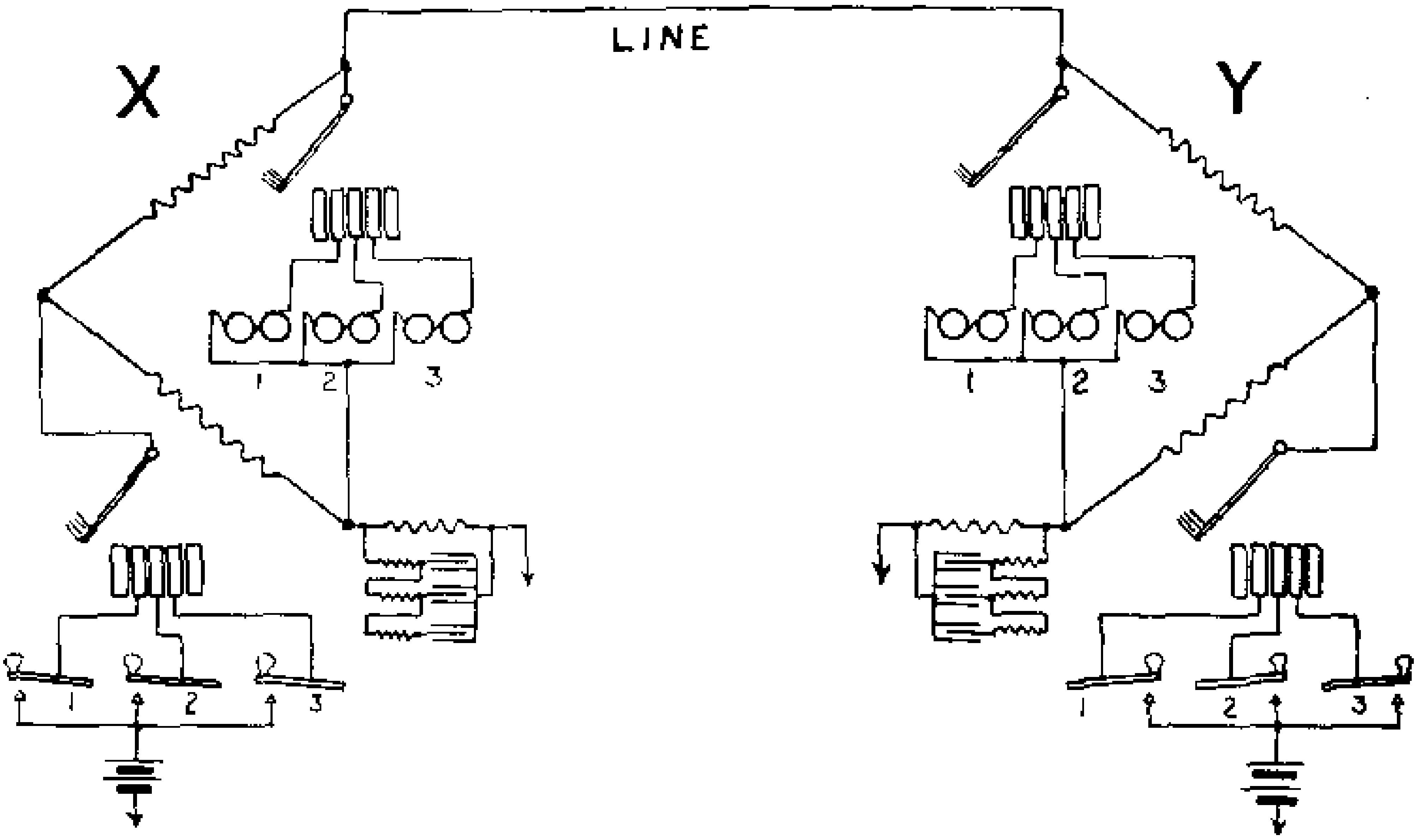


Fig. 99.—Duplex multiplex.

Each station's sending and receiving plate is combined in one distributor, forming two concentric circles. The sending circle is fixed, but the receiving segments are capable of a limited rotating movement to allow of their being turned so as to bring them one, two or more segments, or any fractional part thereof behind the other.

CHAPTER VII.

THE HUGHES TYPE-PRINTING INSTRUMENT.

WE now come to quite a different class of apparatus to that which we have hitherto considered. In the Morse system the signals consist of combinations of currents of long and short duration, representing the letters of the alphabet by a prearranged code, and these combinations have to be translated at the receiving end and the message written down. In the Hughes system the received signals are translated by the receiving *mechanism and printed automatically in Roman type on* a paper slip. No receiving operator (as a translator and writer) is thus required. It also has the advantage that the sending and receipt of a message are simultaneous.

Further, *the combinations of the Morse alphabet are of varying* length. The Hughes signals are all of the same length, each letter consisting of an impulse of current. These impulses are separated by varying intervals of time—the intervals and signals being of equal importance in the scheme. Thus a portion of these must be added to the actual length of the impulse in order to institute a comparison between the working lengths of the signals of the two systems.

The Hughes instrument, in its receiving portion, consists essentially of a continuously-revolving inked wheel, carrying the letters of the alphabet on its periphery, and a paper tape just clear of the wheel. When an impulse of current is received, the paper is raised into momentary contact with the wheel and that letter is printed which is opposite the paper at the time. By the rotation of the type-wheel every letter of the alphabet in turn is brought opposite the slip; the currents sent must, therefore, be so timed as to raise the slip when the required letter is opposite. At the sending end a contact lever, when depressed, makes the necessary connection between the battery and the line, and this lever is actuated by keys, through the intermediation of another simple piece of apparatus which *determines the exact time at which the signal shall be sent.* In each complete instrument the means both of sending and receiving are included; indeed, when the apparatus is sending, its receiving portion is invariably actuated also, so as to give the operator a check upon his sending.

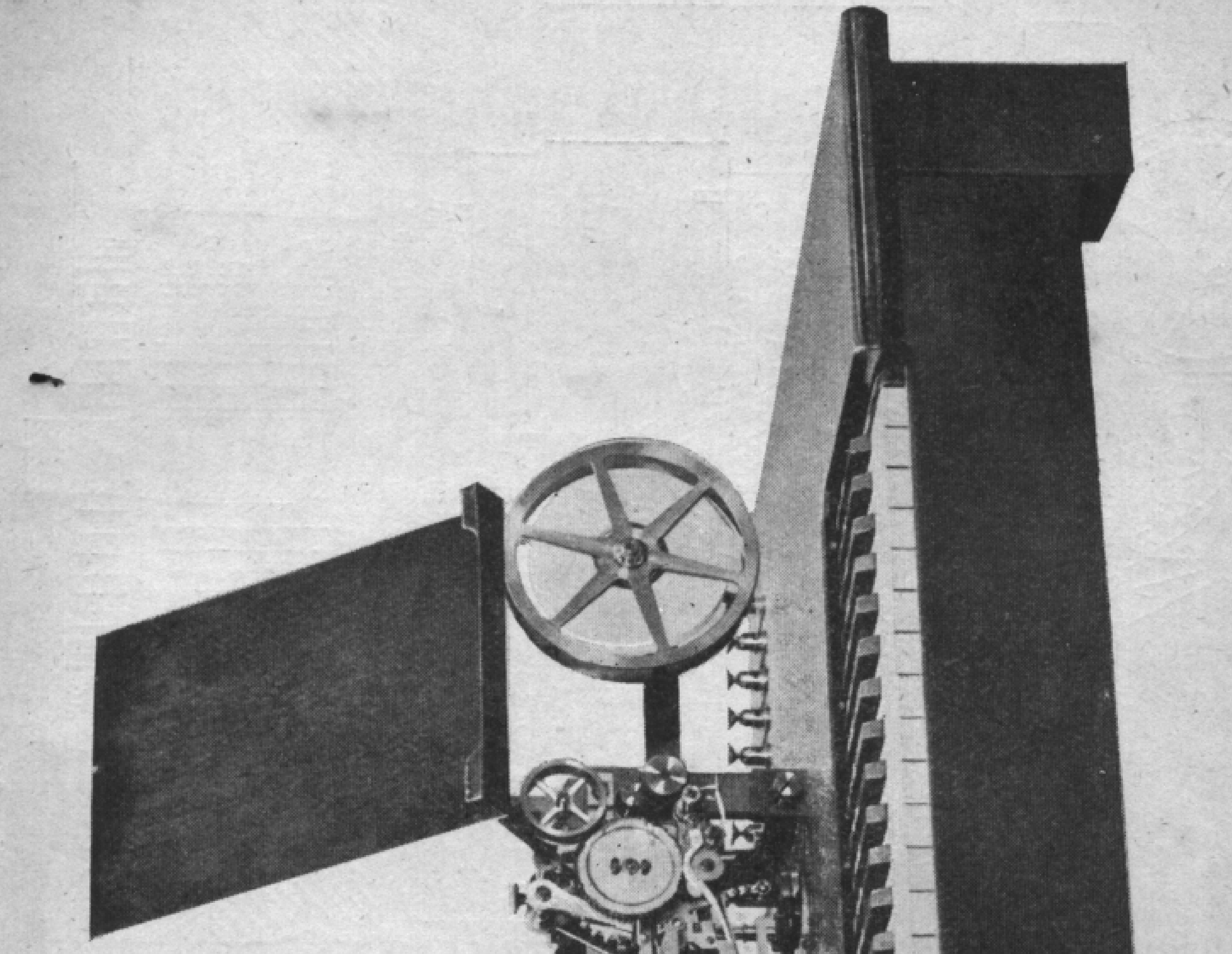


Fig. 100.—Hughes instrument.

The general appearance of the instrument is seen in Fig. 100. Fig. 101 is a front elevation and a section of some of the under parts, whilst Fig. 102 is a plan. The governor and motor are omitted from the two latter figures.

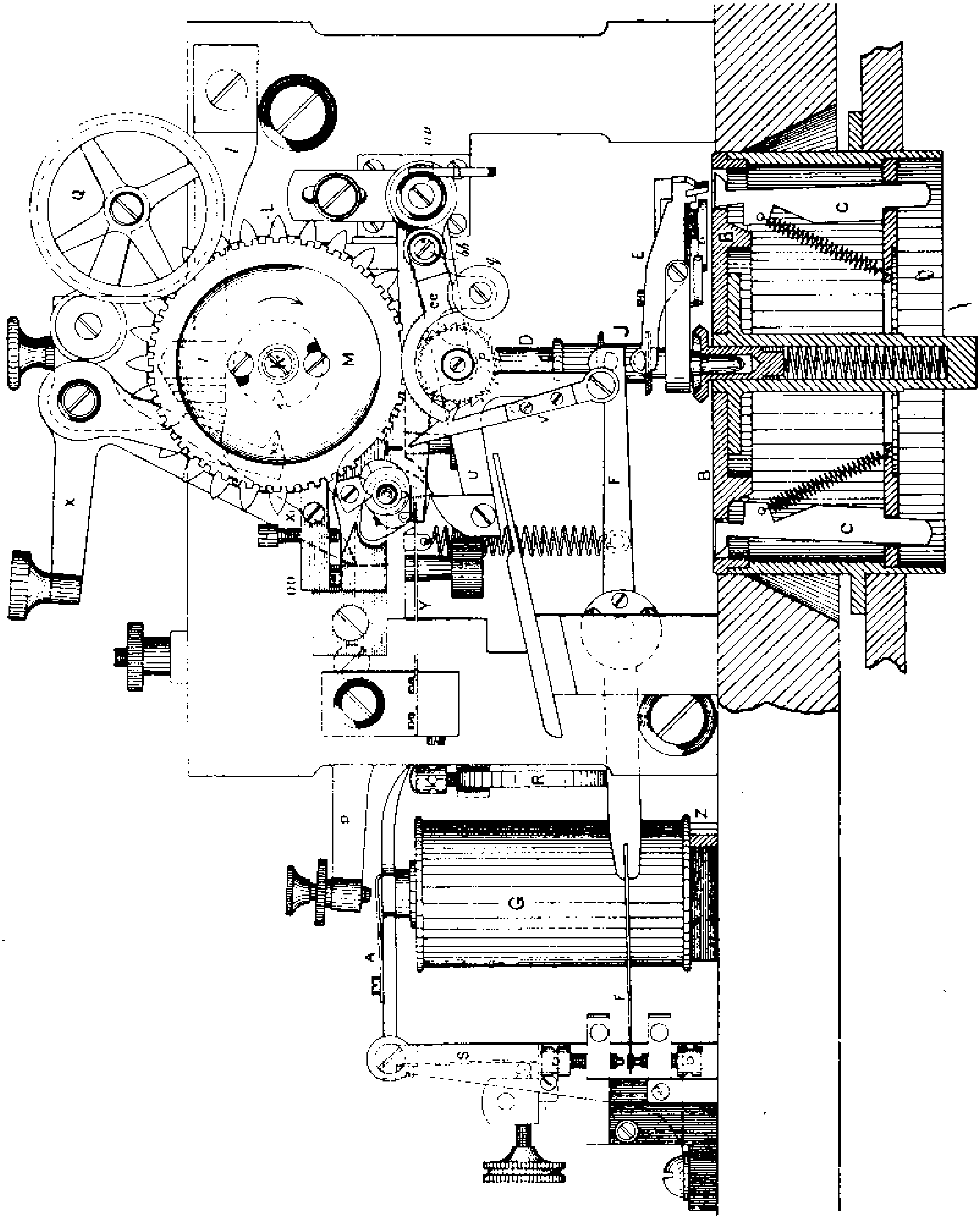


Fig. 101.

Electrical Action.—The electrical action is limited to the releasing of the armature of a magnet—the reverse of the conditions usually obtaining. All the rest of the work of

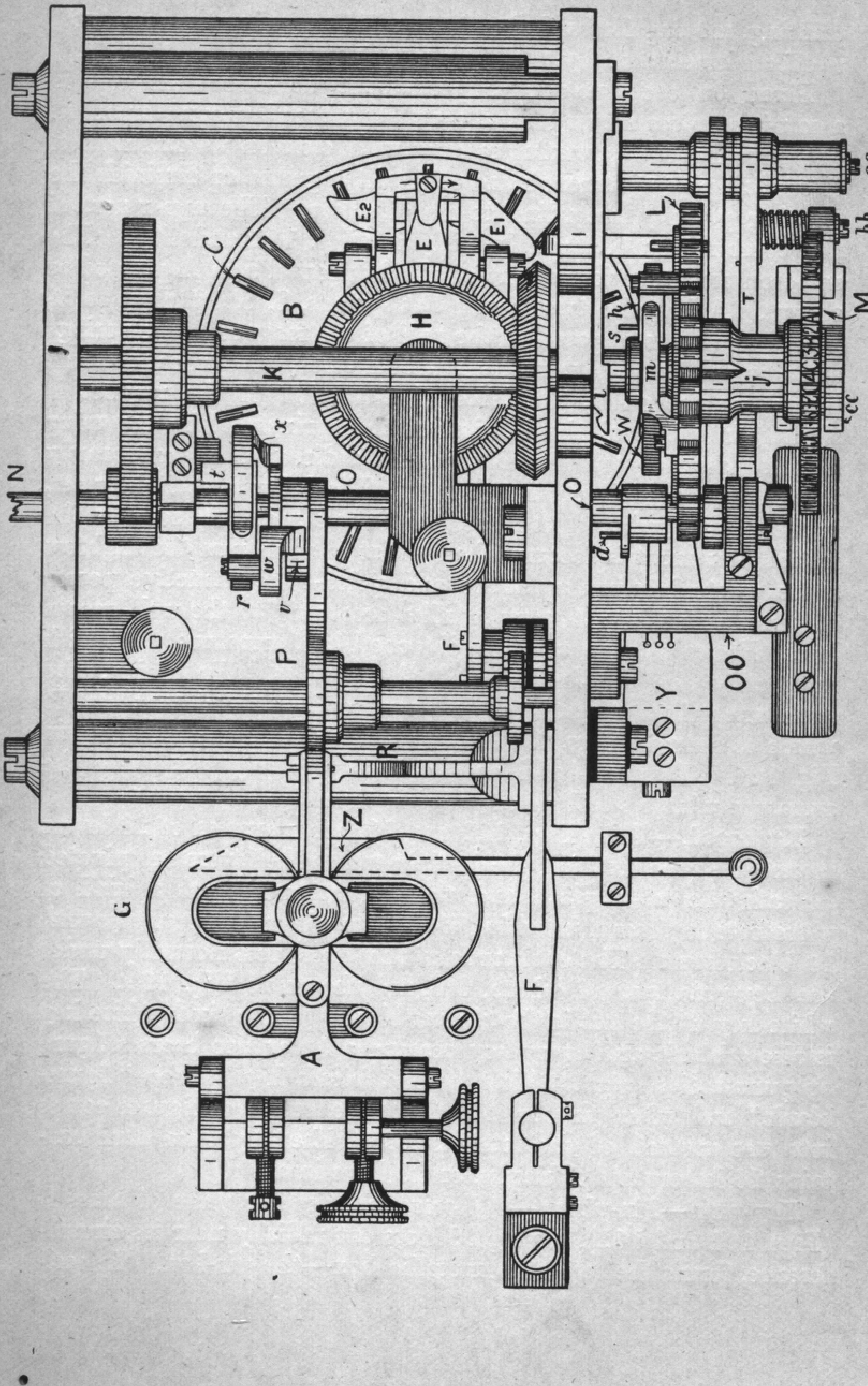


Fig. 102.

printing, moving forward the slip, and of replacing the armature, is effected mechanically.

Fixed on each pole of a permanent horse-shoe magnet is a soft-iron piece serving as a core for the coils wound upon it. We thus have a powerful magnet with coils on its extremities. A current passing through the coils will augment or diminish the existing polarity, according to its direction. The upper part of the combination (G) can be seen in Figs. 101 and 102. The soft-iron armature forms part of the horizontal arm A pivoted as shown. A has also two strong flat springs, S, S, attached to it, whose tension is opposed to the pull of the magnet. The springs are adjusted until a point is reached when, with the armature placed on the poles, the force of attraction of the magnet is slightly in excess of the tension of the springs. The incoming signals pass through the coils in such a direction as temporarily to weaken the pull of the magnet. The balance, so lightly set, is thus destroyed and the armature is released. As soon as the initial movement is accomplished—that is, as soon as the slightest space exists between armature and poles—the attractive power of the magnet falls off very rapidly, according to the well-known law. Hence as soon as it is detached, the armature rises with practically the whole force of the springs. In rising, the armature strikes upward the left-hand end of the detent arm P, which is seen in Figs. 101 and 102, and is shown separately in Fig. 106. This left-hand end of P is normally just above the armature with a small space between them.

Keyboard.—This (Figs. 100 and 108) is a system of 28 levers mounted at the front of the instrument. The levers are pivoted beneath the table plate, and their front ends form a kind of pianoforte keyboard, in which 14 white alternate regularly with 14 black keys. The back ends of the levers rest normally under the key-pins, two of which, C C, are shown in Fig. 100. The white key at the left is the "letter-blank." The sixth white key is also a blank, and every key bearing a letter also bears a figure or punctuation sign. This second blank key is the "figure-blank," and when this is depressed the series of figures comes into use instead of the letter series. The keyboard thus contains 26 letters and 2 blanks, or 28 keys in all.

Key-pins—Pin-plate.—A horizontal circular plate of brass B (Figs. 101 and 102), having 28 slots cut radially near its circumference, forms the top of a metallic box—the pin-box. In each of these slots a steel pin C works, whose lower end rests on the back extremity of one of the keyboard levers; these latter, of iron strip, being necessarily curved to bring their ends in a corresponding horizontal circle. When any key is depressed, the back rises and pushes up its pin, so that the head of the latter is above the surface of the pin-plate.

Chariot.—From the centre of the pin-plate rises a vertical shaft D, having a horizontal brass fitting at its lower end. This fitting provides for the pivoting of a rocking piece E, and the two form the "chariot." The outer portion of E—*i.e.*, that part nearer the circumference of the pin-plate—is normally just clear of the surface of the latter, but if a key-pin rises from its slot and the chariot moves towards it, the outer end of the rocking piece is tilted upwards and its other end correspondingly lowered. On the shaft D, and capable of independent movement thereon, is a loose sleeve J with two flanges. A pin in E rests above the lower flange, and engaging with the upper one is another pin in the contact lever F, which is pivoted as shown, with its further end playing between two contact stops. When the rocking piece is tilted by a protruding key-pin, it draws down the contact arm F by means of the two pins and the sleeve, and causes F to touch the upper contact, and thus send out a current to line.

On the left of its centre of movement, the contact lever carries a brass arm R, shown in Figs. 101 and 102. This, sharing the upward movement of F, at the instant of sending a signal strikes off its own armature, thus actuating its own receiving apparatus.

It will thus be seen that the key-pins arranged radially round the pin-plate ensure that the signals shall be sent out at the proper time.

Type-wheel Axle.—The upper end of D carries a bevel wheel H (Fig. 102), which engages with a similar one on the horizontal shaft K running from the back and through the front of the instrument. This shaft is the type-wheel axle. The two bevel wheels are of the same diameter, and K drives D at exactly the same rate as the type-wheel axle itself is driven. The chariot, therefore, is continually revolving over the pins.

On the forward end of K is carried a combination of the type-wheel M, a correcting-wheel L, and the means by which the combination shares or abstains from sharing in the motion of the axle. Fig. 103 gives a section of the combination, and Fig. 104 the star-wheel and other parts. They are also shown in Figs. 101 and 102.

The type-wheel carries the letters of the alphabet and two blank spaces, as arranged on the keyboard. This divides M up into 28 parts, so that for every unit of movement — $\frac{1}{28}$ of a revolution — we advance one letter. Further, in each space between two letters is a figure or other sign.

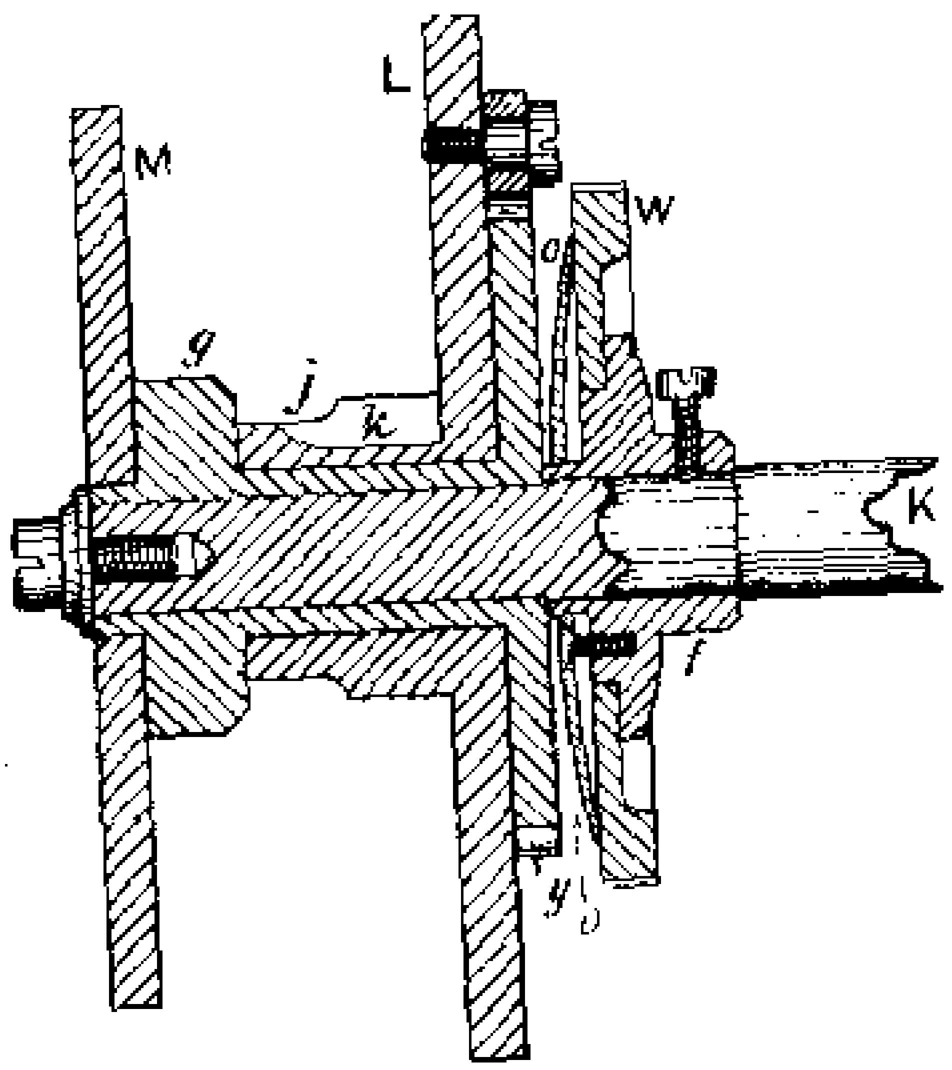


Fig. 103.— Details of type-wheel, &c.

At the back of the type-wheel is the correcting-wheel L having 28 teeth. With an exception to be explained further on, the type- and star-wheels are fixed together, and, therefore, move together, but both are loose on the axle K. They may, therefore, be stationary whilst the axle is continually revolving.

The other member of this combination, the ratchet-wheel W (Figs. 103 and 104), is loose on K, but is held friction-tight between the collet *f*, which is fixed to the axle by a screw, and the dished disc *o*. Ordinarily, therefore, W moves with the axle, but is capable of independent movement. The latter movements are always slight—due to the shifting of the

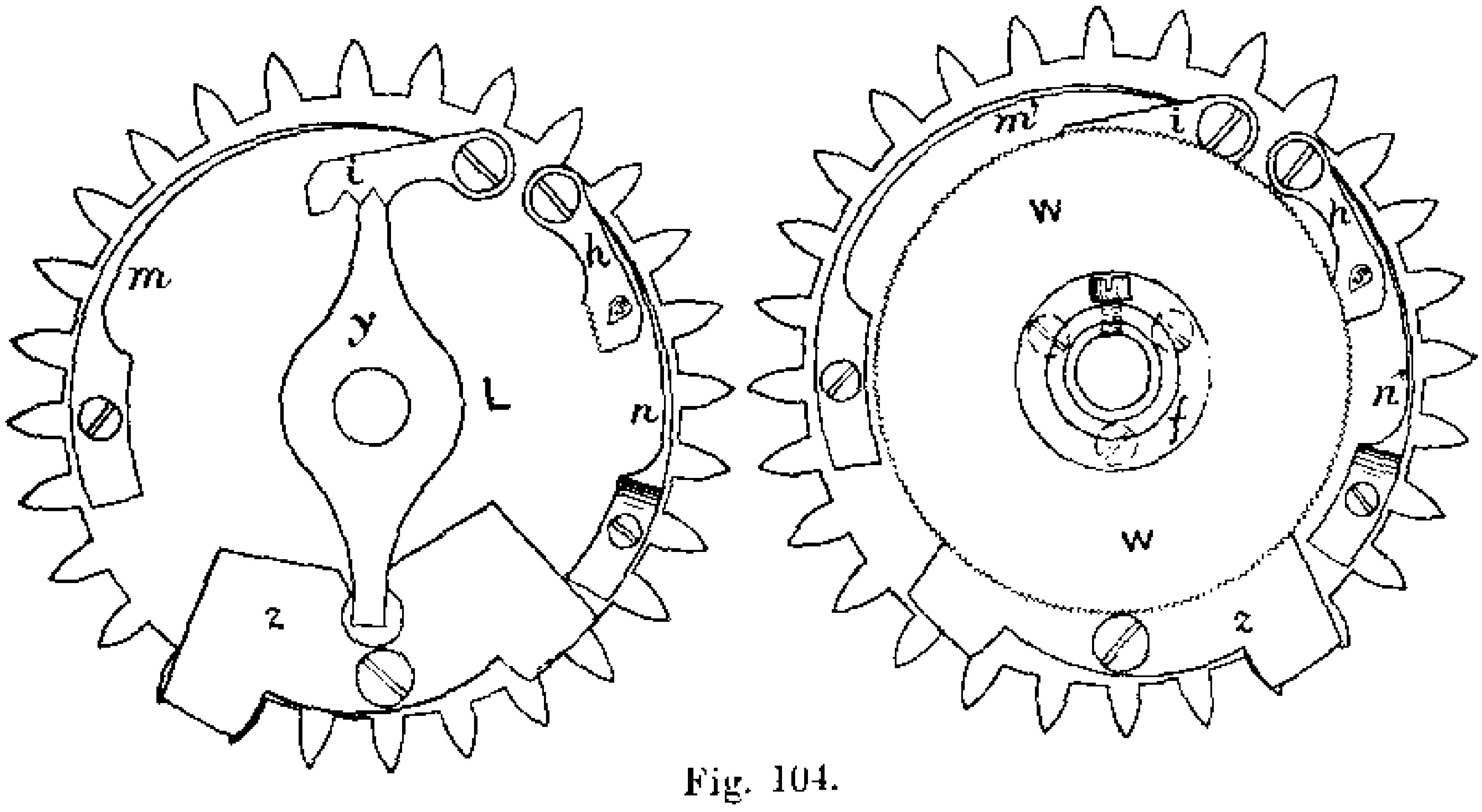


Fig. 104.

correcting-wheel — so that, with these exceptions, W shares in the rotation of K.

Printing Axle.—The driving axle N, on which is mounted the armature of the electric motor, enters the back plate of the instrument as shown in Fig. 102. It carries a small toothed wheel, by which it drives the type-wheel axle. It is then continued through a bearing, and on the other side of this carries a larger toothed or ratchet-wheel *r*. The diameter of the axle is then reduced, and after continuing for about half an inch ends in a point. In perfect alignment with N is O, the printing axle proper, and this extends from the ratchet-wheel through the front of the instrument, where its extremity is carried by the bracket O O, Fig. 102. At the inner end it is hollow, so as to pass over as a kind of sleeve the pointed termination of the driving axle, which termination forms the back bearing for O. The two axles, although so closely placed to each other, are perfectly independent, and are normally quite separate; the driving axle revolving continuously and the printing axle remaining at rest. The printing axle is shown separately in Fig. 105. At the left hand is the hollowed end. At this end O carries two arms at right angles to its length. One of these arms carries the click *t*, and the other a spring *x*, tending to force the click upon the teeth of the ratchet-wheel *r*. Fig. 106 shows the relation between the printing axle, the detent arm P and the armature A of the electro-magnet G. To do this clearly, the right-hand portion of O is omitted, only the cam *e* and the two arms being shown. Mounted on the bearing in which the driving axle runs is a double inclined plane *u* of tempered steel, and close to this is one end of the detent arm P already referred to. The click *t* has a projection (seen in Fig. 102) which normally is slightly to the left of the summit of the inclined plane, and would run down the latter, but a shoulder *w* on the arm carrying the click banks against a shoulder *v* on the end of the detent lever, and thus prevents the movement. If this end of P be lowered the click will slide down the plane and engage with the ratchet-wheel. The printing axle will, therefore, be carried round with the driving axle, but only for one revolution: since on the completion of one turn the projection on the click will encounter the right-hand side of the double inclined plane, and in running up this, will disconnect the click from the ratchet-wheel. The momentum acquired will carry the projection just over the summit of *u*, and it is there stopped by the shoulder *v* of the detent arm which has resumed its normal position. The lowering of this end of P is effected by the striking up of its other end, which action is effected by the release of the armature. Hence, for every current received, the release of the armature allows the printing axle to participate, for one revolution only, in the movement of the driving axle.

The printing axle, shown separately in Fig. 105, protrudes from the front plate and carries the printing cam *a*, the paper-moving cam *b*, and the correcting cam *c*; whilst at the other end is another, the armature replacing cam *e*.

The printing cam executes part of its revolution in the fork of the printing lever T. This lever, movable on the pin *a a*, carries the printing roller *p*, the guide *q*, and an ivory fork, *c c*, which latter moves in the pin *b b*, and is kept normally pressing on *p* by a spiral spring. Beneath the arms of this fork the printing roller *p* has two finely-toothed wheels. The paper slip, brought round the guide *q*, passes between these wheels and the fork, being firmly gripped at the edges thereby. As the cam revolves it gradually raises T until the paper on *p* is brought into contact with the type-wheel. The printing cam then moves clear of the fork of the printing lever, and the latter falls to its position of rest.

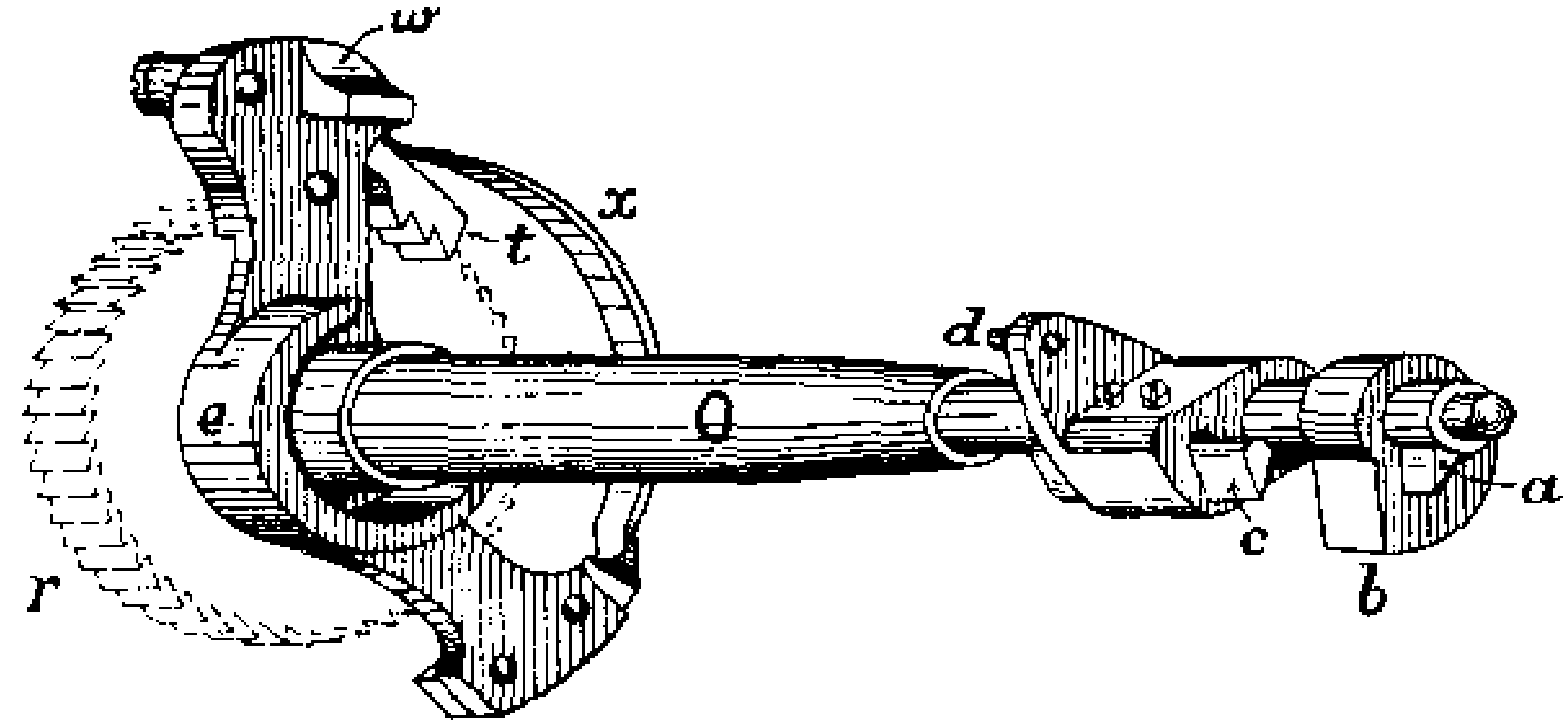


Fig. 105.—Printing axle.

The paper is moved forward by the cam *b* in the following manner:—Another lever, U (Fig. 101), is movable on the pin *a a*, and has a long arm extending vertically downwards. This arm carries the paper-moving click V. The printing roller *p* has, in addition to the paper-gripping wheels, a click-wheel at the back, and V is kept constantly engaged with this by means of a spiral spring. A flat spring (not shown) keeps U when at rest with its projection pressing against the cam *b*. When the latter moves round it forces the lever U downwards, and the click pulls the printing roller round a space.

The correcting cam is a bar of steel, *c*, fixed as shown, its cross-section being such as to form a sharp edge at one side and a rounded portion opposite. As it turns, its path intersects that of the correcting-wheel L (Fig. 101). The edge, therefore, enters between two of the teeth, and then the cam gradually turns round so that its length (from the edge to the rounded portion) exactly occupies the space between two teeth.

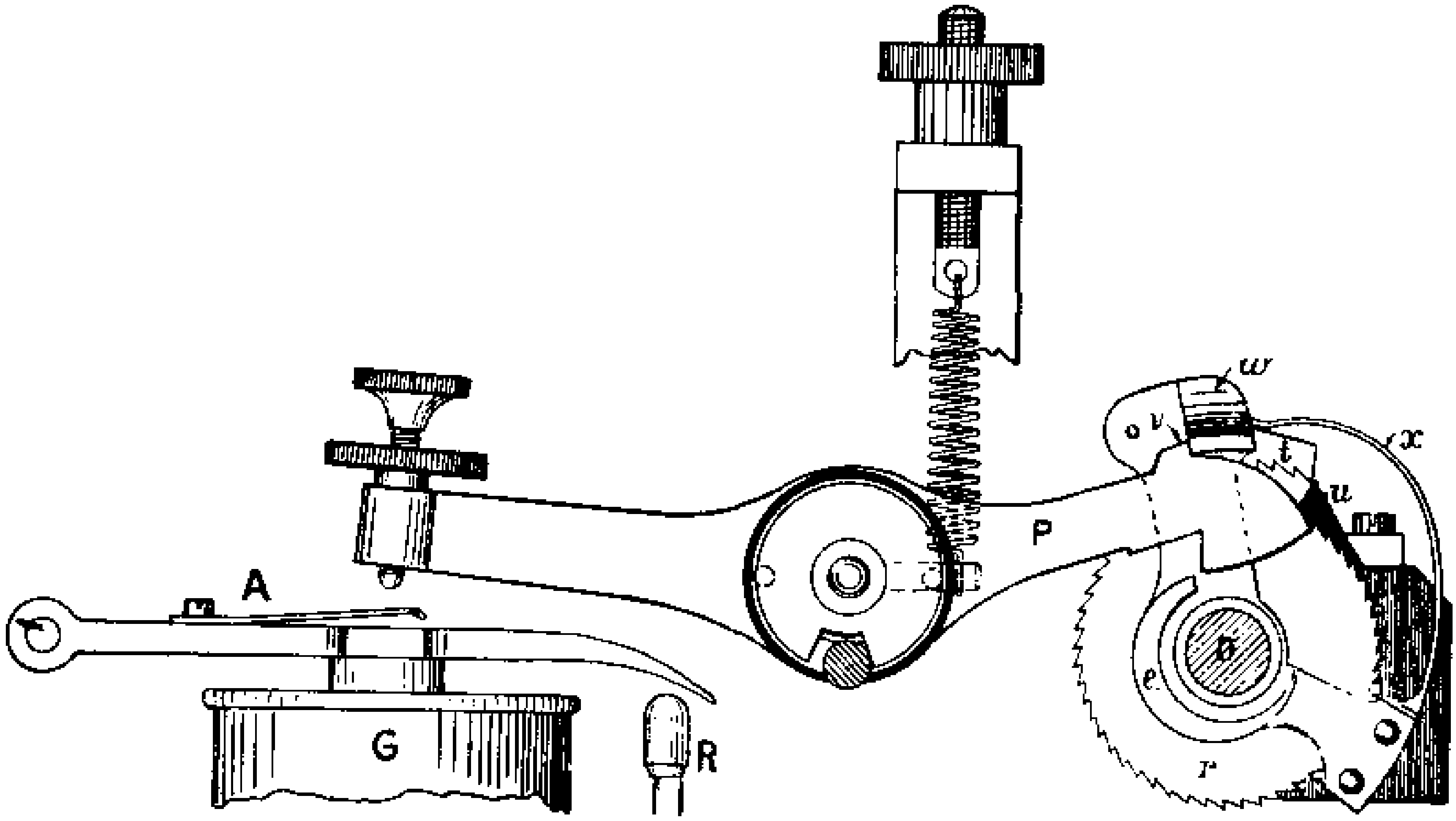


Fig. 106.—Details of detent arm, &c.

Now, if the accord between the sending and receiving instruments be perfect, the position of the correcting-wheel will be such as to allow the cam to take up its position without any trouble. If, however, the signal be late, L will be slightly in advance of this proper position; hence, when the cam begins to place itself so as to exactly fill the space between two teeth, it will force the star-wheel slightly backwards. If the receiving instrument is running slightly slow, the cam urges the star- and type-wheels forward in advance of the axle. Every signal passing through the instrument thus acts (if necessary) as a corrective.

The correcting cam has another function. In its position of repose it presses down the spring Y (Figs. 101 and 102), making contact with it. As will be seen from Fig. 108, this connection is in the direct path of the coils of the electro-magnet. After being released the armature has to be replaced, and the action of replacing sets up in the coils a momentary current. The direction of this current is such as to weaken the magnet, and thus to cause the armature to be again released. But the correcting cam, in turning, quits contact with the spring Y, so that, *during the replacing of the armature, the circuit of the coils is* broken, and this momentary "magneto-current" is prevented.

At the inner end of the printing axle, and just in front of the two arms, is a fourth cam, *e*, which restores the armature across the poles of the magnet. It does this by the medium of the detent lever P. As we have seen, the arm carrying the click *t* is normally held against a shoulder piece on the right-hand end of P. When the other end is struck up by the rise of the armature, this right-hand end is lowered, and allows the projection on the click to slide down the left side of the double inclined plane *u*, and to engage with the ratchet-wheel *r*. Towards the end of the revolution of the axle the cam *e*, as seen in Fig. 104, rises under the right-hand end of P, and pushes it up. The other end, descending, replaces the armature. This effected, the cam *moves a little further round, so that the way may be clear for the* detent arm to fall in response to the next signal. In the normal position the left-end hand of P just clears the armature lever so as to break electrical connection.

Letters and Figures.—We have seen that the type-wheel carries a double set of characters. Taking the unit of movement as $\frac{1}{28}$ of a revolution, the letters of the alphabet and two blank spaces occupy 28 equidistant points on the circumference of the type-wheel. Thus, starting from zero, the first current will give us the letter blank, the fourth the letter C, the fifth D, and so on—that is, the type-wheel always moves unit distance or some multiple of it. Between each pair of letters, however, is a figure or sign, and these form another series of 26 and two blanks, the lengths of the two latter being added to those of the other letter series. Each figure is thus $\frac{1}{28}$ of a revolution from its neighbour, but, with the type-wheel in its normal position, the figure series never touches the slip.

The type- and correcting-wheels constantly move together, one having no movement independent of the other, saving in the case of the change over. The type-wheel M is fixed to the tube g (Fig. 103), which passes back through the correcting wheel, and there carries the arm y. The upper end of y is brought to a sharp edge, and engages in one of two notches in the pawl i, which is kept pressing tightly down by the spring m. The other end of y engages with a piece, z, movable on the centre screw, and having two projections or extensions. In the position shown to the right in Fig. 104 the right-hand projection covers the space between two teeth of the star-wheel. The correcting cam, in entering this space, forces the projection inwards, thus causing y to shift into the right-hand notch of i. As y is rigidly attached to the type-wheel by means of the tube g, the type-wheel naturally shares in this slight movement, which is exactly $\frac{1}{56}$ of a revolution, or half the space between one letter and the other or between one figure and another. This is half the unit movement of the type-wheel. The act of forcing the right-hand extension of z inwards naturally throws the left-hand one over the space between two other teeth. A reverse movement of y follows when the correcting cam enters the latter space. Hence, with the arm in one notch, the instrument will print letters, and, in the other, figures. When the letter-blank key is depressed, the type-wheel, if at figures, will be shifted to letters, and when the figure blank is put down the wheel is shifted to figures—the two spaces thus alternately covered by the piece z corresponding with the letter and figure blanks of the keyboard.

Zero-adjusting Lever.—X, X_1, X_2 are the arms of the zero-adjusting lever, by which the type-wheel may be stopped and brought to zero, the type-wheel axle revolving continuously. The operation is constantly necessary, both at starting work and after "running out."

Governor.—It is absolutely necessary that the sending and receiving instruments shall run together, or in synchronism. To keep the speed of the instrument constant during the variations in the load, due to the movements of the contact lever and the printing axle, is the object of the governor, illustrated in Fig. 107. The circle described by the balls when the instrument is actually doing work is of a certain size. When the instrument runs light, and the speed therefore tends to increase, this circle becomes larger. Brakes of tow fitted upon the arms of the governor then rub against the inner surface of the steel ring

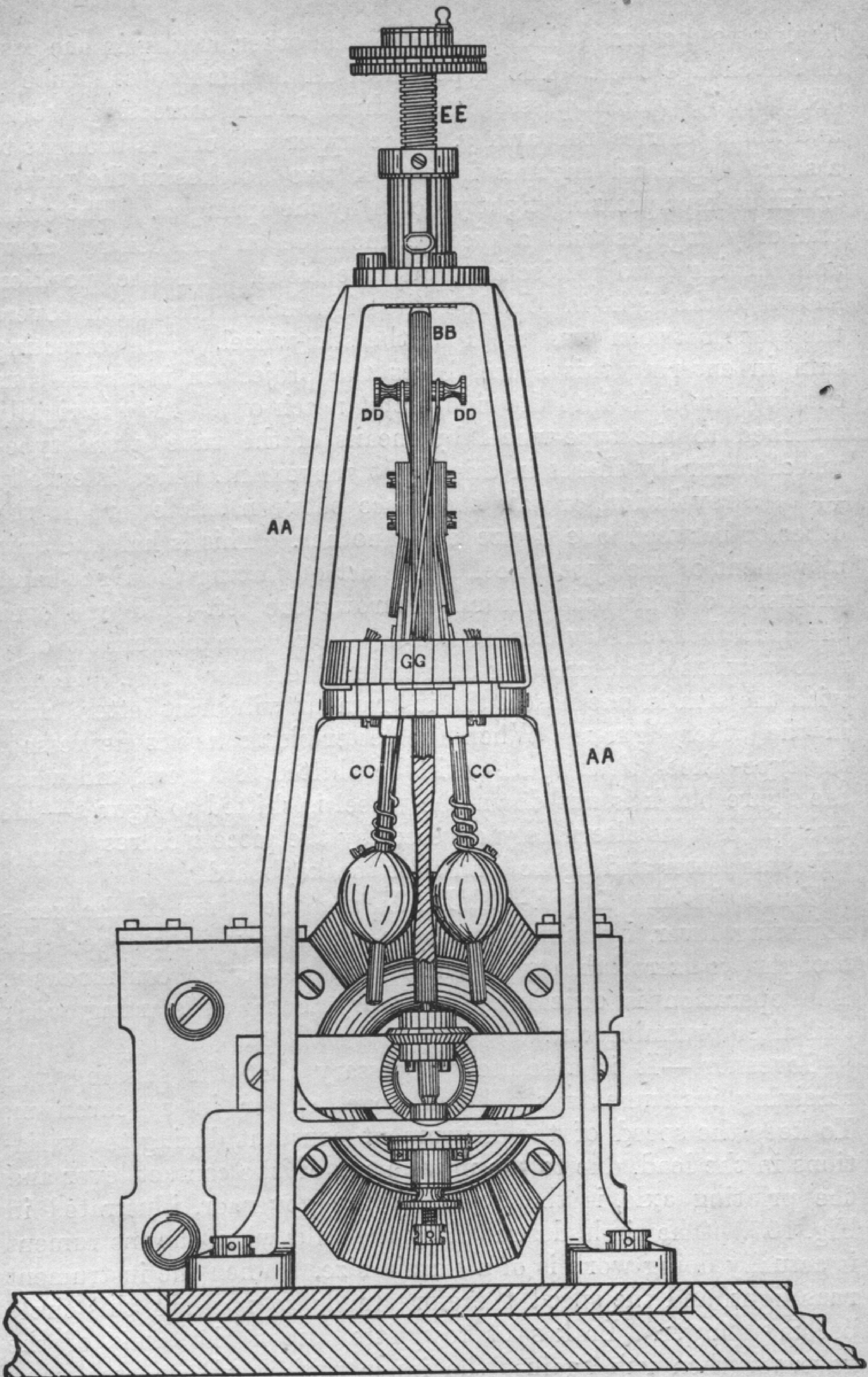


Fig. 107.—Motor and governor.

G G, thus introducing friction. The actual speed at which the instrument runs is from 100 to 125 revolutions of the chariot per minute.

General.—From Fig. 108 it will be seen that the path of the received current through the apparatus is from the line terminal, the contact lever, the lower contact, the motor switch (the motor running, hence this switch to the "on" position), *via* framework of instrument, to detent arm P and the corecting cam *c*, thence by the spring Y through motor switch again, and to the 5-position switch. Assuming this to be at position 1, the current passes through the electro-magnet coils to earth. The armature itself is connected to earth through the resistance coil; as soon, therefore, as A is released, it makes contact with the detent arm,

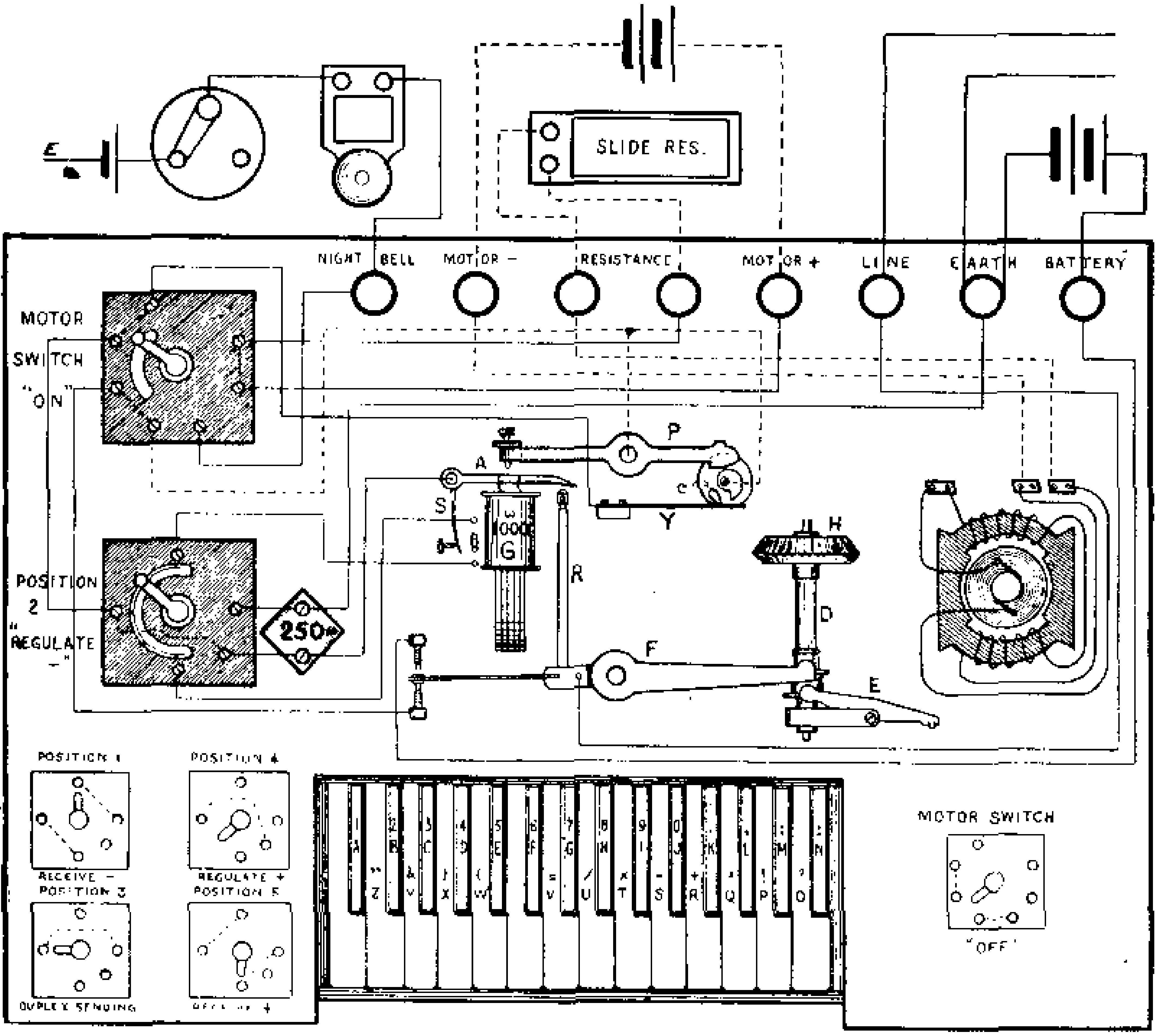


Fig. 108.

and the frame is put to earth through the resistance coil. The path of the coils is at the same time severed by the movement of the correcting cam which breaks contact with the spring Y.

With the lever of the 5-position switch at "1" the incoming current passes through the coils in a certain direction, suitable for receiving zinc or negative currents from the line. Position 5 simply reverses the ends of the coils for the receipt of positive currents. Positions 2 and 4 bring earth in front of the coils (through the resistance coil). Position 3 puts a direct earth on from the line terminal. This latter position is for use when the instrument is sending on a duplex set.

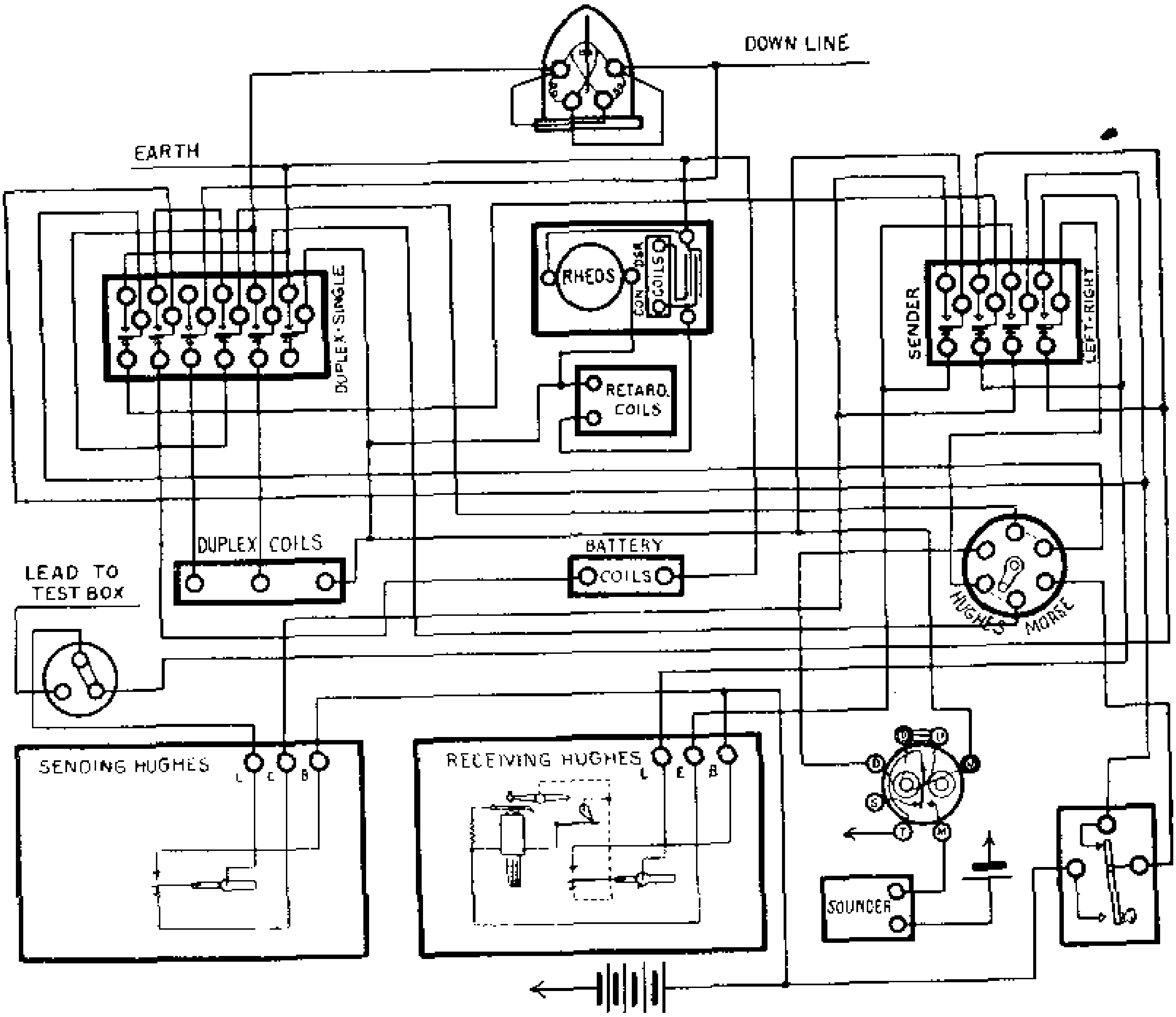


Fig. 100.—Hughes: duplex (bridge) or single.

The driving power of the original instrument was a weight. As an unvarying force, this, of course, cannot be surpassed. The winding-up arrangements, however, were cumbrous, and the operation frequent and laborious. More train-work was also involved, each instrument having its own table. Electric motors are used exclusively at the foreign gallery of the Central Telegraph Office, and are very convenient; the whole instrument, motor and all, being self-contained, can be carried and placed on any table. Pneumatic pressure has been tried as a motive power, but has been abandoned in favour of electrical driving.

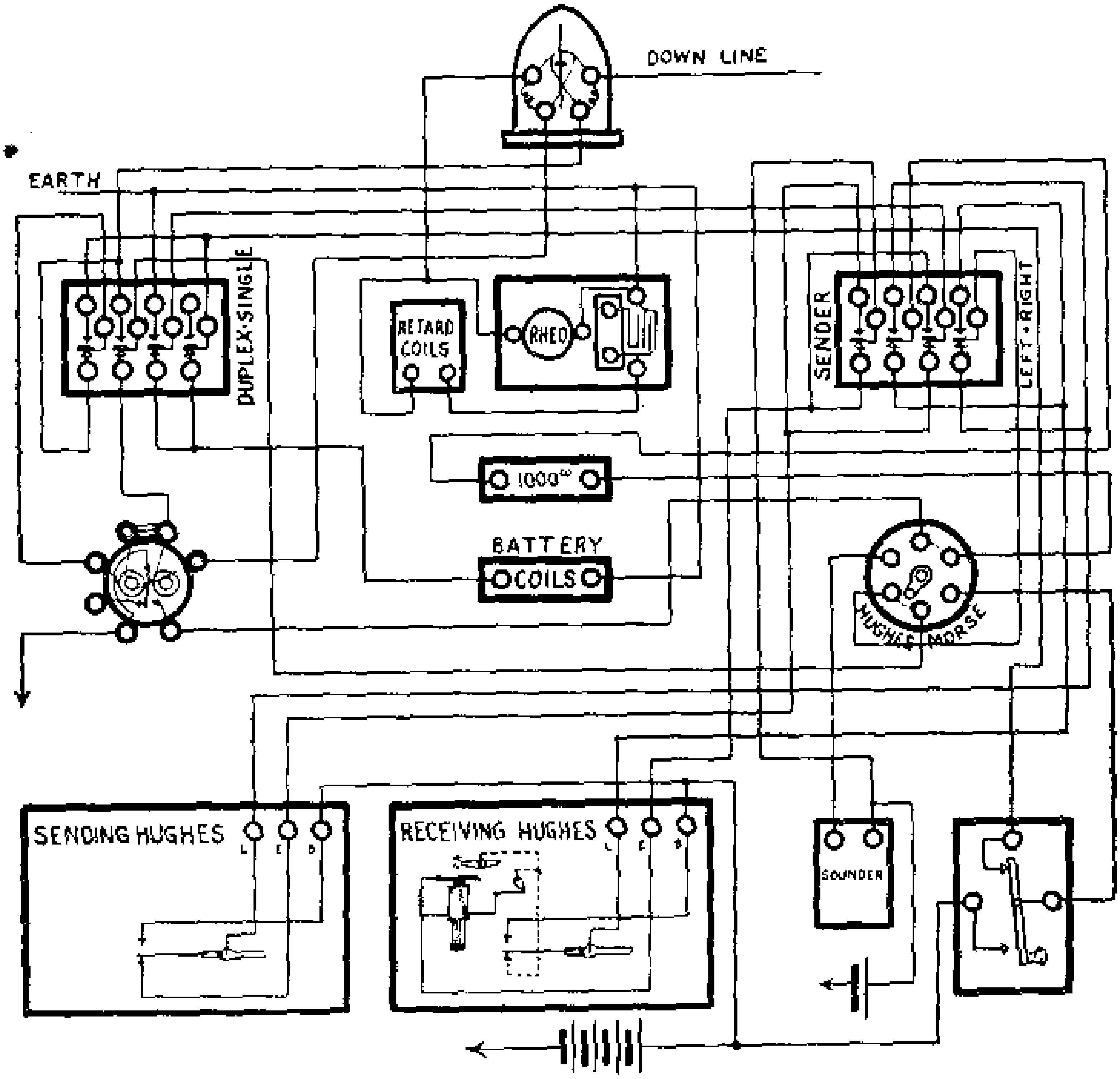


Fig. 110. – Hughes: duplex (differential) or single.

When a station calls he gives the signals "blank N" repeatedly. These two keys are at opposite points of the keyboard, and their continued depression sends out a rhythmical succession of currents. The other station, in replying, repeats these signals, and one or other office asks for "blanks" in order to set his instrument at the same speed as the other. The distant office responds by repeatedly depressing his blank key, thus sending a single signal per revolution. If the receiver is running at the same rate he will get a clean slip, the first signal starting his instrument at the blank position, and succeeding ones simply repeating it. If, however, he is running too fast or slow, the first blank will be followed by A or Z, and so on. He therefore adjusts accordingly. On getting a clear slip he puts his switch to position 2 or 4, so as to cut off the received blanks from his electro-magnet, and thus allow his instrument to run a few revolutions without correction. On again allowing the blanks to enter, any slight difference in speed will have been multiplied, and will show up. A finer adjustment is then made. The type-wheel should run for 10 revolutions without correction, without running out when the blanks are again allowed to enter.

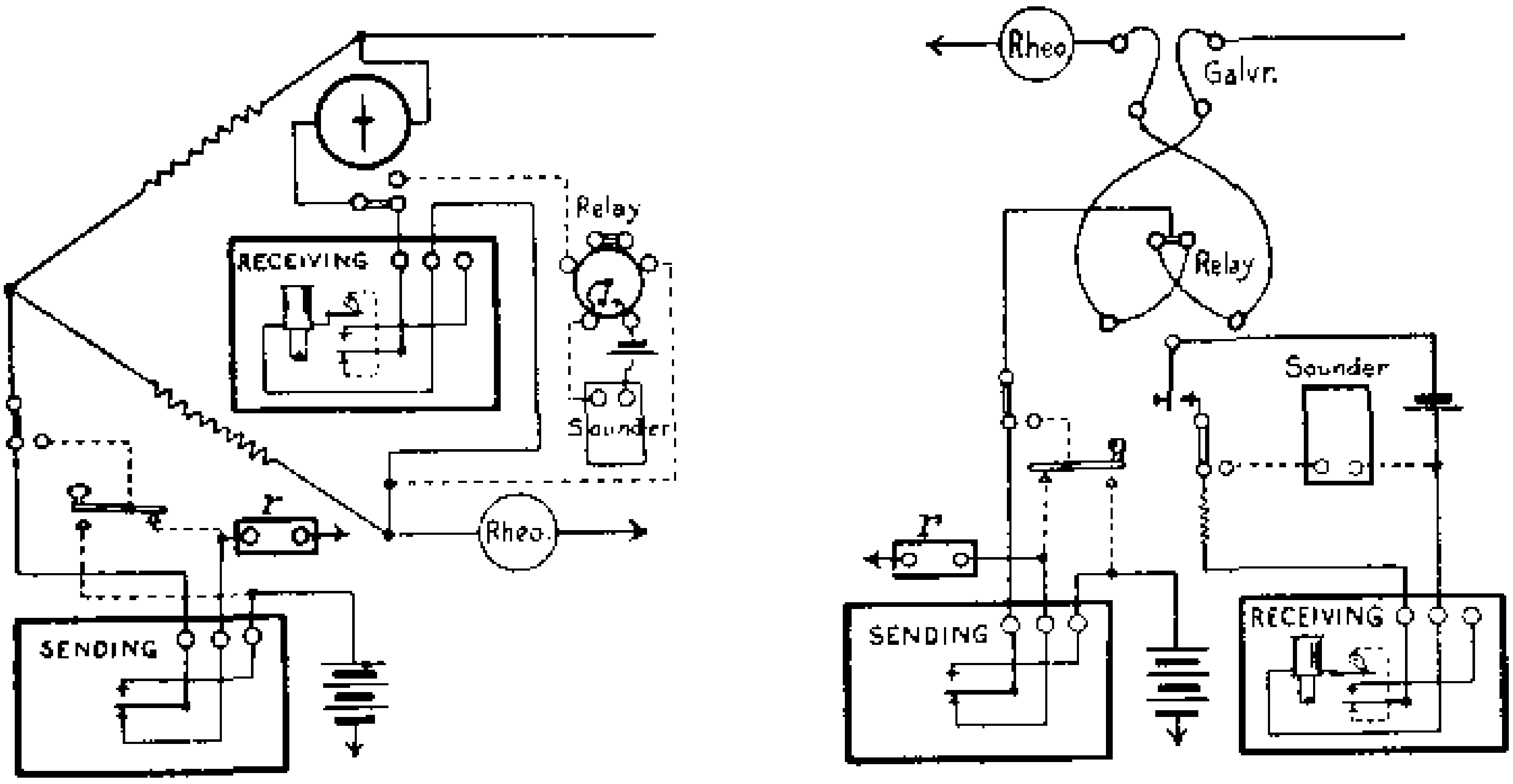


Fig. 111.

The accord between the sending and receiving instruments is generally spoken of as synchronism, but, from the definition given in Chapter VI., isochronism is the more correct term. In the multiplex of Chapter VI. similar segments are touched simultaneously by the brush, and the sent-out signal is received on a later segment. Synchronism, therefore, obtains. Regarding the letters of the Hughes type-wheel as the equivalents of the segments, each signal is sent and received on similar segments. The receiving instrument must, therefore, be run behind the sender by an amount equal to the retardation of the line.

Duplex.—This is effected on both the bridge and differential plans, the former being generally employed on the Hughes circuits working to the Continent, and the latter on the few lines worked Hughes in this country.

As the electro-magnet is not wound differentially the first plan is the simpler, the receiving instrument and galvanometer being placed in the bridge. When the differential system is employed a standard polarized relay is used, and the receiving Hughes worked in the local circuit. Figs. 109 and 110 give the full connections, whilst Fig. 111 gives a skeleton of both. The Morse is for use in balancing, and for various speaking purposes.

The employment of repeaters on long circuits is dealt with in Chapter XII.

CHAPTER VIII.

THE BAUDOT SYSTEM.

This is a multiplex type-printing system, combining the common use, by several operators, of the same line and printing arrangements somewhat similar to those of the Hughes instrument.

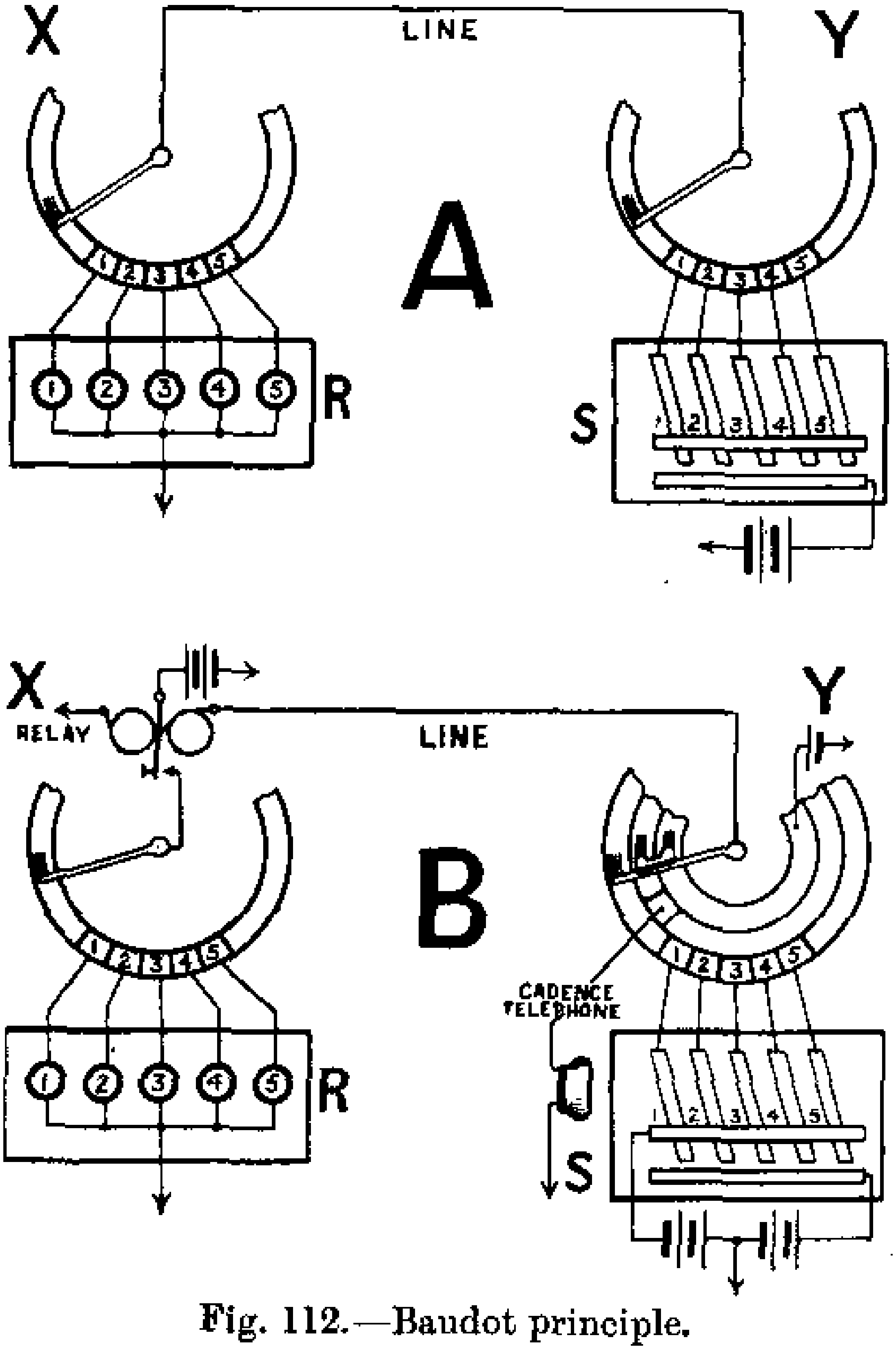


Fig. 112.—Baudot principle.

The principle of multiplex telegraphy is treated of in Chapter vi., its application in the present system is easily seen.

At A in Fig. 112, two distributors at stations X and Y are connected by a line. Five segments, 1, 2, 3, 4, and 5, are insulated from each other and from the rest of the ring, and the two trailers are running in synchronism. At Y the segments are connected to a set S of five keys or tappers, beneath which is a metallic bar joined to the positive pole of an earthed battery. At X the segments are connected to a set R of five electro-magnets. If one, two, or all the keys be held down whilst the trailer passes over the series of segments, a current or currents will pass to line and be received on the corresponding electro-magnets at X. That is, R_3 will respond to the depression of S_3, and so on.

B, in the same figure, is the same arrangement worked double current. If none of the keys be depressed, five negative currents will be sent when the trailer passes. Any key held down simply determines that a positive current shall be sent from that particular key. Thus, if Nos. 2 and 5 be depressed (*i.e.*, held down whilst the trailer passes over the whole series) a negative current will be sent from 1, a positive from 2, negative from 3 and 4, and positive from 5. At X a polarized relay is necessary, because the electro-magnets R, being non-polarized, will be actuated by currents in any direction. The relay tongue moves to marking, in obedience to currents Nos. 2 and 5, and to spacing in response to 1, 3, and 4. Nos. 2 and 5 electro-magnets will therefore be actuated by currents sent from the relay tongue. That is, the arrangement at B is simply that of A worked double current.

These five keys and magnets represent, not five *arms*, as we have previously considered in Chapter VI., but one arm only. The five keys are small finger tappers, any or all of which may be depressed together by the fingers of both hands, and the set forms the sending portion of the arm. Similarly the five electro-magnets, with a great deal more mechanism, form the receiver or translator. Whether we put down one, two, or all the keys, the passage of the trailer over the segments always results in the sending to line of five currents. Each such set of five constitutes a letter, the different letters being obtained by varying the order and direction of the currents. The alphabet is thus an equal-letter one—the letters are all of the same length.

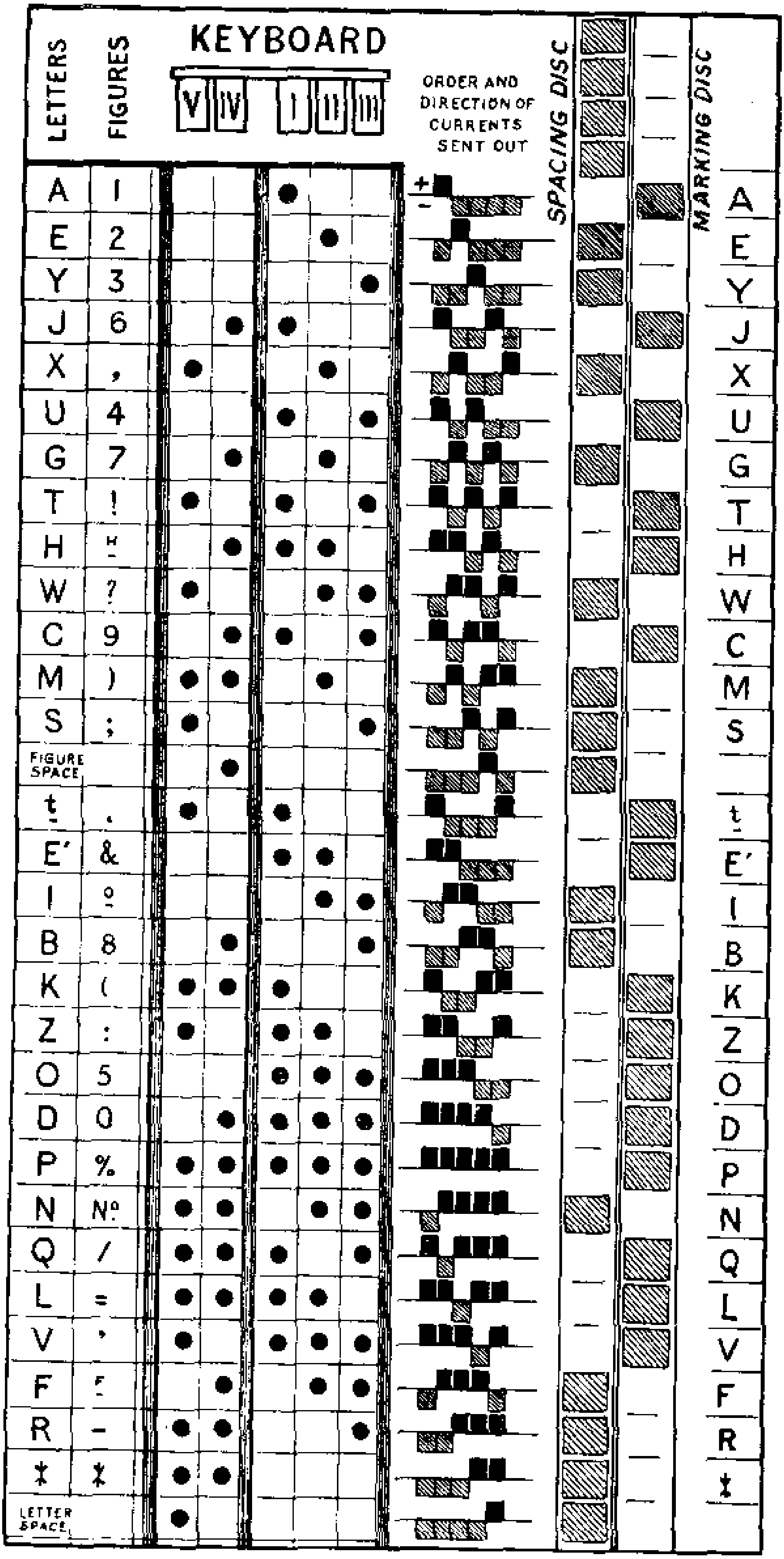
At the receiving end the electro-magnets corresponding to the spacing currents remain unaffected, whilst those corresponding to the marking ones are actuated. Both those at rest and those responding, however, enter into the formation of the letters.

The sending operator must have his five keys in the proper formation, so that when the brush sweeps over the segments, it may transmit the currents in the necessary directions, and as soon as the brush has passed he must get the next combination ready. That is to say, the depression of each group of keys to form the required combination must take place rhythmically, one letter being sent per revolution of the trailer. This is effected by the device shown at the sending station at B in Fig. 112. Two additional rings are fitted and these are connected together by the passage of another set of brushes. To the single insulated segment shown, a telephone receiver is connected and placed near the operator's ear. A click given in the telephone then indicates that the trailer is about to pass over the working segments.

Fig. 113 gives the alphabet in use. The five keys of the sender are divided into two sets by the "send" and "receive" switch and numbered as shown. The two on the left thus send their currents last. The order in which the letters of the alphabet are arranged corresponds with the order in the receiver as we shall see. The ninth and tenth columns represent the marking and spacing discs of the receiver. The final column repeats the letters to facilitate cross-reading of the diagram.

For other arms, additional sets of five segments are required; the number of arms workable depending on the character—length, retardation, &c.—of the line. For circuits with a retardation (ignoring other factors for the nonce) not exceeding one segment—equivalent to about $\frac{1}{70}$ second—four-way or tetrode is practicable. The work involved in recording a letter is not finished by the reception of the five signals in the receiver. These merely arrange the translating mechanism which then selects and prints the required character. These operations therefore need time beyond that occupied in the passage of the currents. Hence, it would be useless to send a second series into the translator until it has printed the first and is ready for the next. The system, therefore, ingeniously dovetails the operations of the several arms, one receiver completing its work whilst the currents are being distributed to the receivers of the other arms.

It will be seen that whilst both systems are based on a common principle, there is this great difference between the Baudot and the Morse multiplex, that in the former each of the



LETTERS	FIGURES	V	IV	I	II	III
A	1			●		
E	2				●	
Y	3					●
J	6		●	●		
X	,	●			●	
U	4			●		●
G	7		●		●	
T	!	●		●		●
H	H̲		●	●	●	
W	?	●			●	●
C	9		●	●		●
M	)	●	●		●	
S	;	●				●
FIGURE SPACE			●			
t̲	.	●		●		
E'	&			●	●	
I	º				●	●
B	8		●			●
K	(	●	●	●		
Z	:	●		●	●	
O	5			●	●	●
D	0		●	●	●	●
P	%	●	●	●	●	●
N	Nº	●	●		●	●
Q	/	●	●	●		●
L	=	●	●	●	●	
V	'	●		●	●	●
F	F̲		●		●	●
R	-	●	●			●
‡	‡	●	●			
LETTER SPACE		●				

Fig. 113.—Baudot alphabet, &c.

five signals constituting a letter is perfectly continuous and not broken up into a series of rapidly-succeeding impulses.

The London-Paris lines worked Baudot are arranged for tetrode, and the following description applies particularly to this number. For synchronising, one station only—the correcting office—sends correcting currents; the other office receiving these is the corrected station. Each distributor, however, sends correcting currents to each of its own receivers.

Sender.—This is comparatively simple. Fig. 114 is a general view, and Fig. 115 gives the arrangement of one of the tapper keys and a diagram of connections. When the trailer passes, the two keys on the left necessarily send their currents last. To prevent the release of these before the contact has been made, Nos. 4 and 5 keys are kept down (even if the fingers are raised) until the trailer has actually passed by means of the device shown. A permanent magnet, N S, is placed beneath each of the two keys. The S pole has a soft iron attachment, S^1, carrying a coil, and in the key itself is a soft iron armature, F. When the tapper is depressed this magnetic arrangement keeps it down. The current passing through the cadence telephone also passes through the coils beneath the two keys, and in such a direction

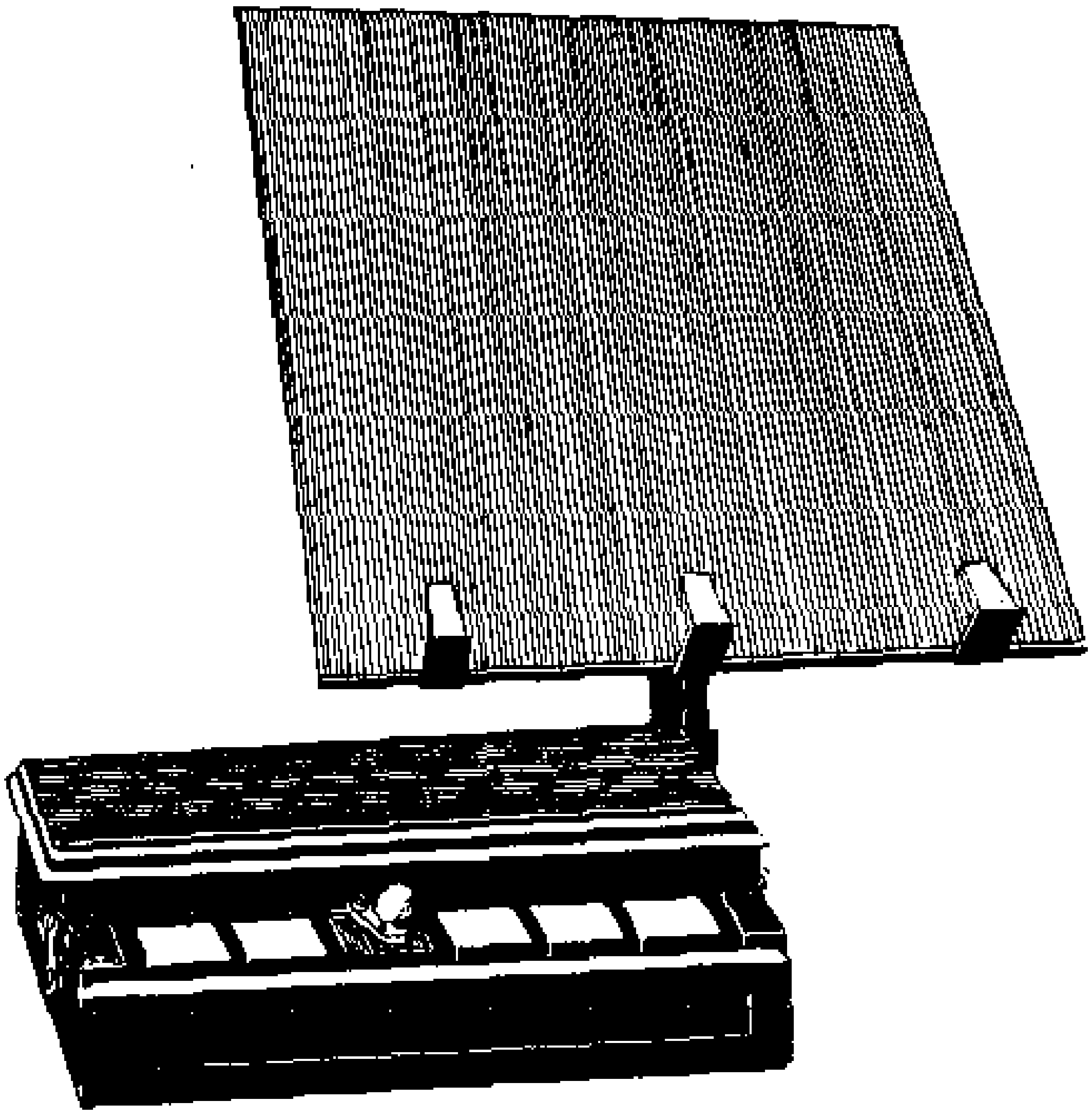


Fig. 114.—Baudot sender.

as to induce an N in attachment S^1. Hence, when this current passes, the keys are released. In another form of sender the arrangement is slightly different, and is applied to all the keys, but the principle is the same.

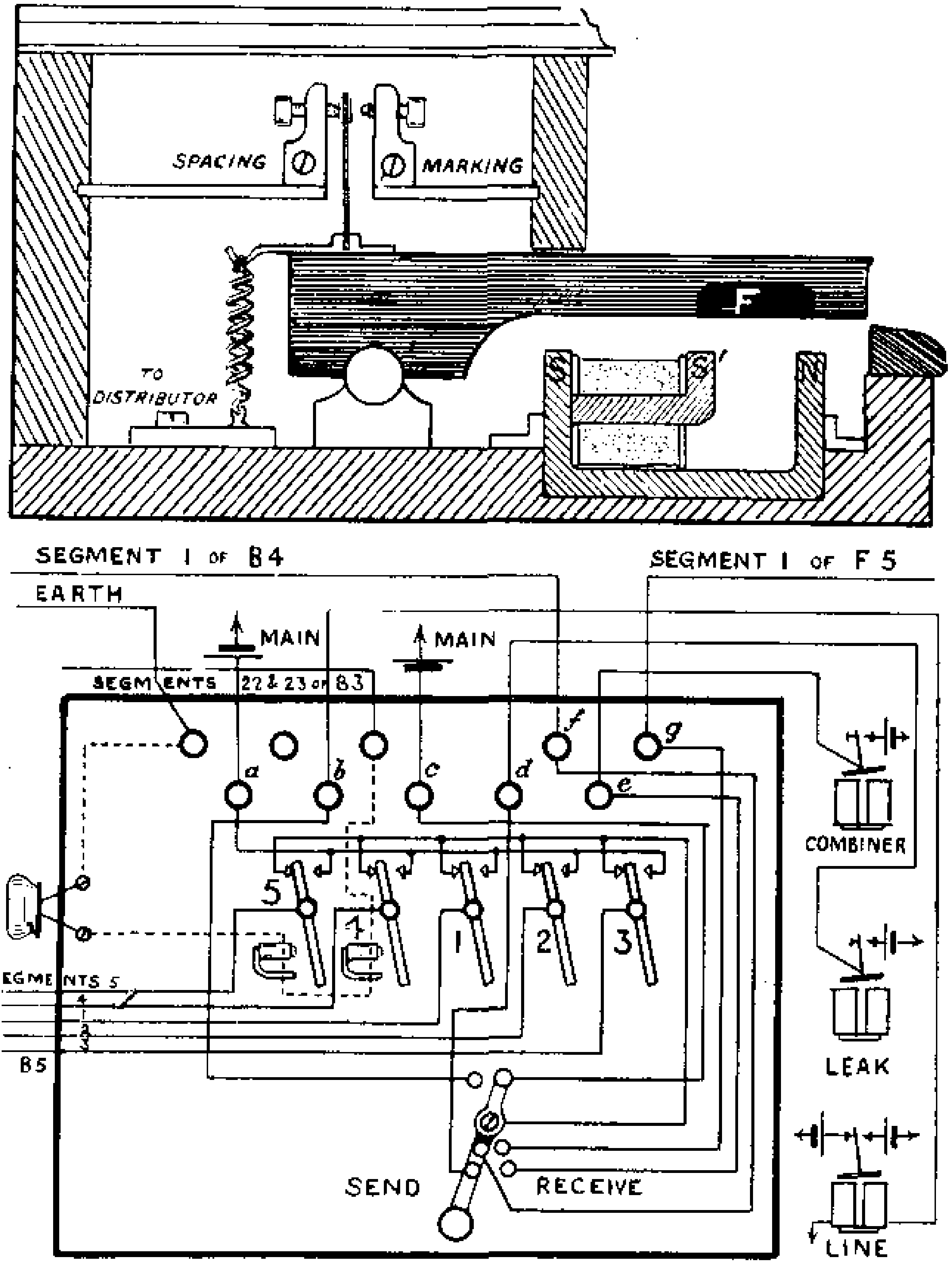


Fig. 115.

Receiver.—A general view of this is seen in Fig. 116. The wheel shown in the centre is the type-wheel, and the printing arrangements are mounted below and behind this. An enlarged view of this portion is given in Fig. 120. Fig. 117 shows the instrument as seen from the left-hand side, giving the more important parts and a section of the type-wheel, &c. Fig. 118 is a view from the top, whilst Fig. 119 gives the upper portion of the mechanism as seen from the front.

A (Fig. 117) is one of five (bar) electro-magnets. The series is placed in line, and corresponds with the receiving electro-magnets R of Fig. 112. The coil cheeks are of soft iron, and the armature is pivoted in the back cheek. A flat spring, D, normally keeps B off the front cheek. Attached to B is a brass lever, C-shaped, ending in a curved finger. In front of the electro-magnets are five steel levers E each having a vertical and a shorter horizontal arm. F is a flat steel spring with a notched piece at its free end, and in this notch the edge of the shorter arm of E normally engages. When A is actuated, the armature, moving downwards, brings with it the curved lever C, whose extremity strikes down the horizontal arm of E by a smart tap. The spring allows the arm to descend and just clear the notch,

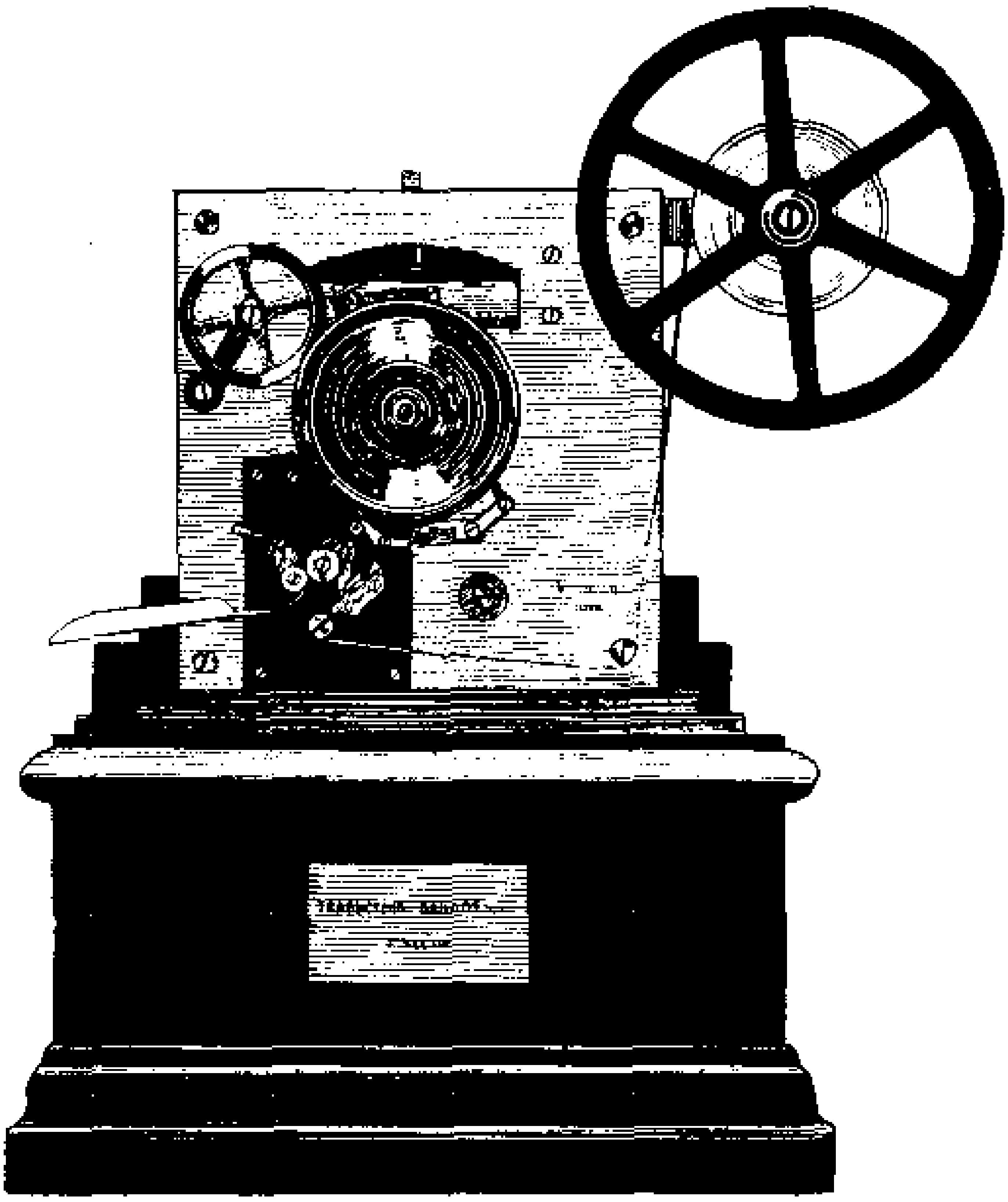


Fig. 116.—Baudot receiver.

the under side of which forms a kind of inclined plane, down which the pressure of the spring tends to cause it to slide.

G (Fig. 117) is one of five "seeking" levers, each of which is fixed on a rod, H, capable of sliding movement between two plates. Each has a curved head-piece, so that the heads of the whole form an arc of a circle, and their lower ends or feet are curved to the right. From Figs. 117, 118, and 119 it will be seen that the levers are capable of two movements, individual and concerted. Each, any, or all may slide from back to front, and *vice versâ*, when other mechanism allows. The concerted movement is received from, or given to, a sixth lever, W, to the left of G 1. This lever has a head like the others, but no lower extension. It is not capable of sliding motion, but can turn to a limited extent on its axis, this movement being communicated

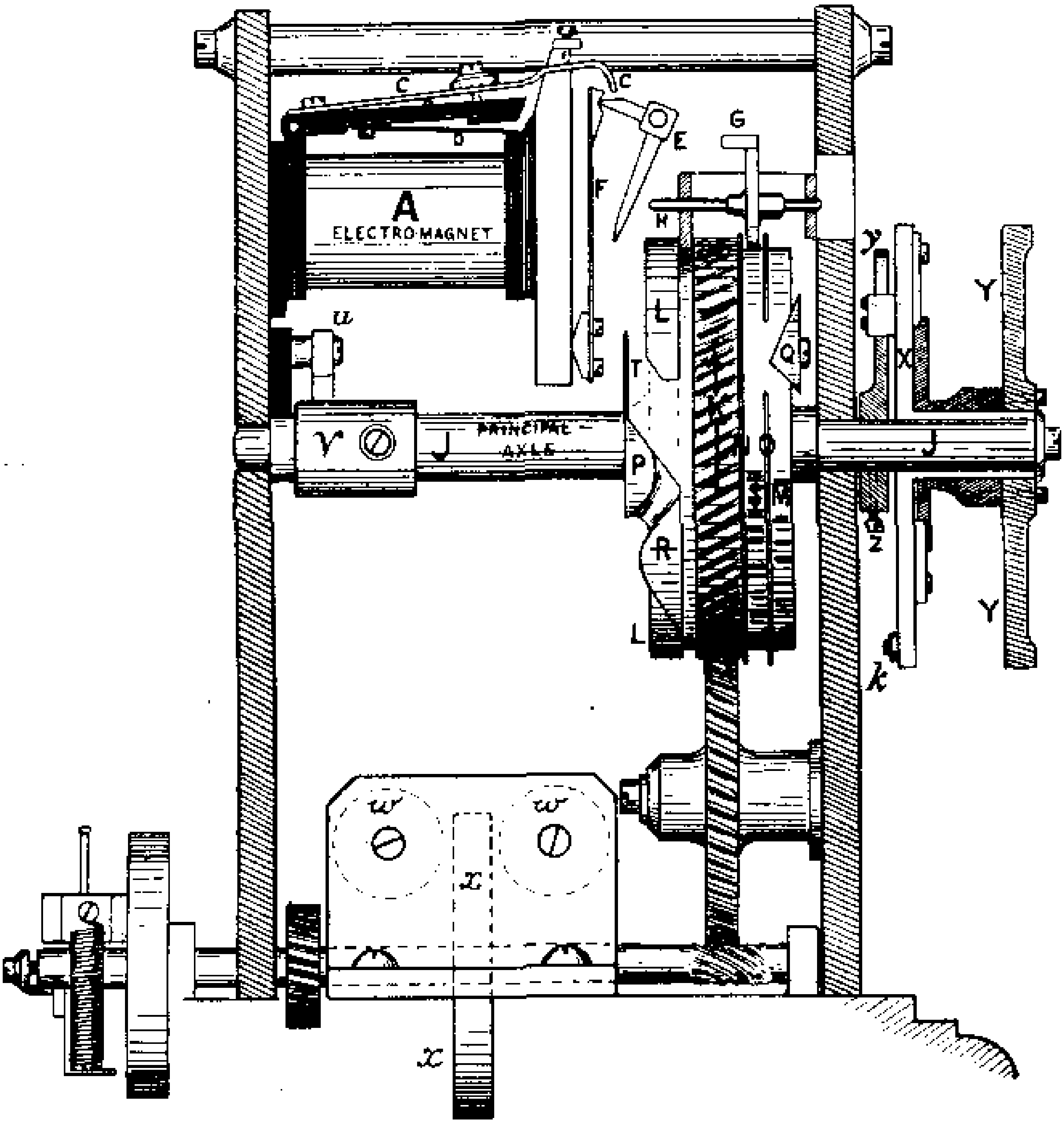


Fig. 117.—Receiver: details.

to an outer arm, V. The latter is furnished with a flat spring U which tends to move the head of W to the right. This movement is communicated to the levers G 1, G 2, &c., by their heads, which their individual sliding motion never disconnects. This may be seen in Fig. 118, where three levers are in the normal position, and the first and fifth are pushed forward.

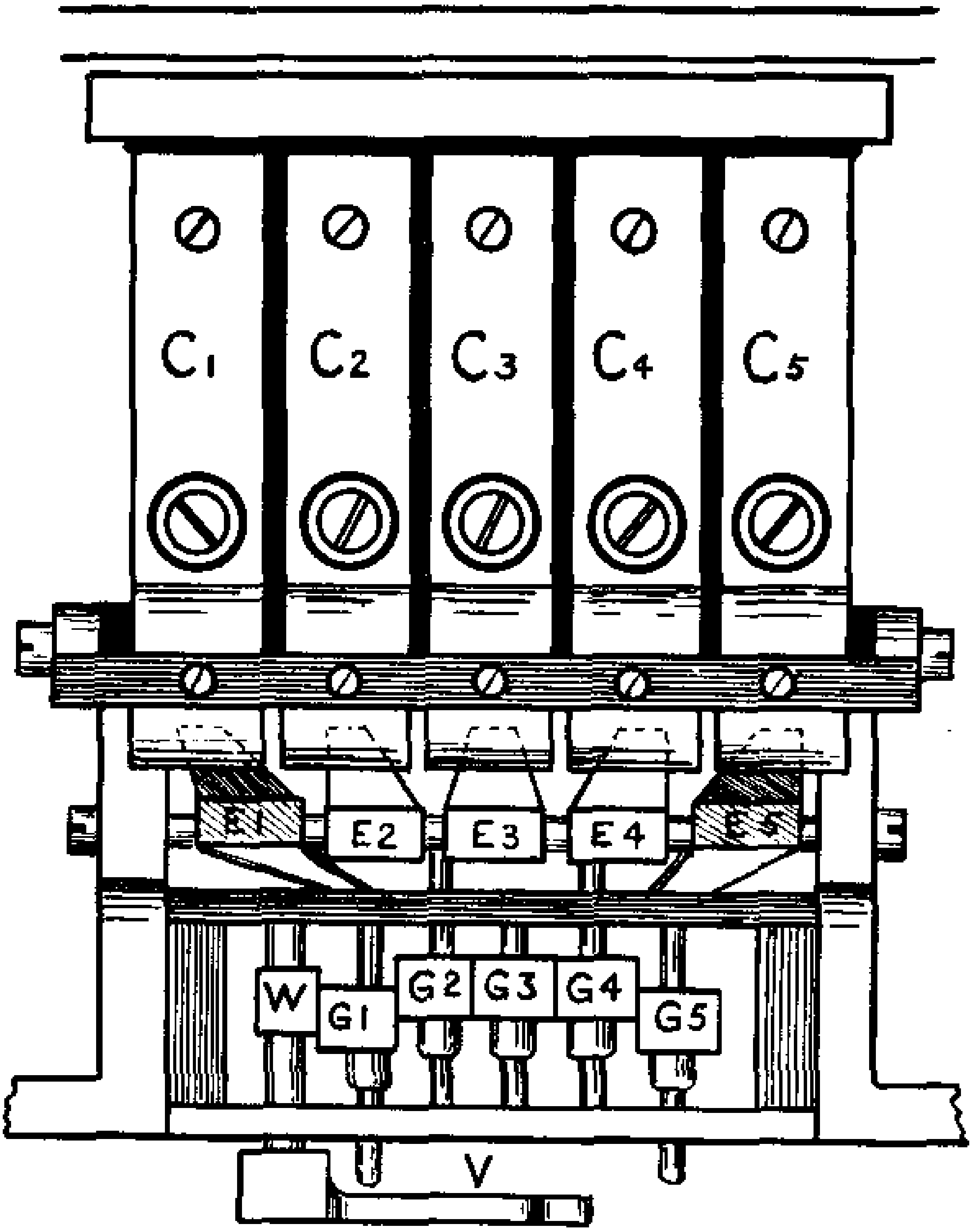


Fig. 118.—Receiver: details.

Also, if any motion should carry the feet of the levers to the right, their heads will move W to the left, and the arm V will rise.

J, seen in Fig. 117, is the principal axle, and carries the "combiner" inside and the type-wheel and other parts outside. The combiner consists, first, of a toothed-wheel K by which the axle is turned. S and M are two steel discs, having on their peripheries a series of hollows. Two thin discs of steel, N and O, separate M from S and S from K. O is cut away in the region of the cam Q. If the system be turned (clockwise) the lower ends or feet of the levers G will simply run in the groove, the bottom of which is formed by the disc S. Or, rather, this groove — the spacing groove — will revolve with the levers stationary at its upper portion. M is the base of another, the marking groove. When the inward point of Q is at the top of its journey any one of the sliding levers, if pushed to the right, will be free to pass from the spacing to the marking groove; and when the combiner has made a nearly complete revolution the sloping surface of cam Q will cause the levers to return to the spacing groove.

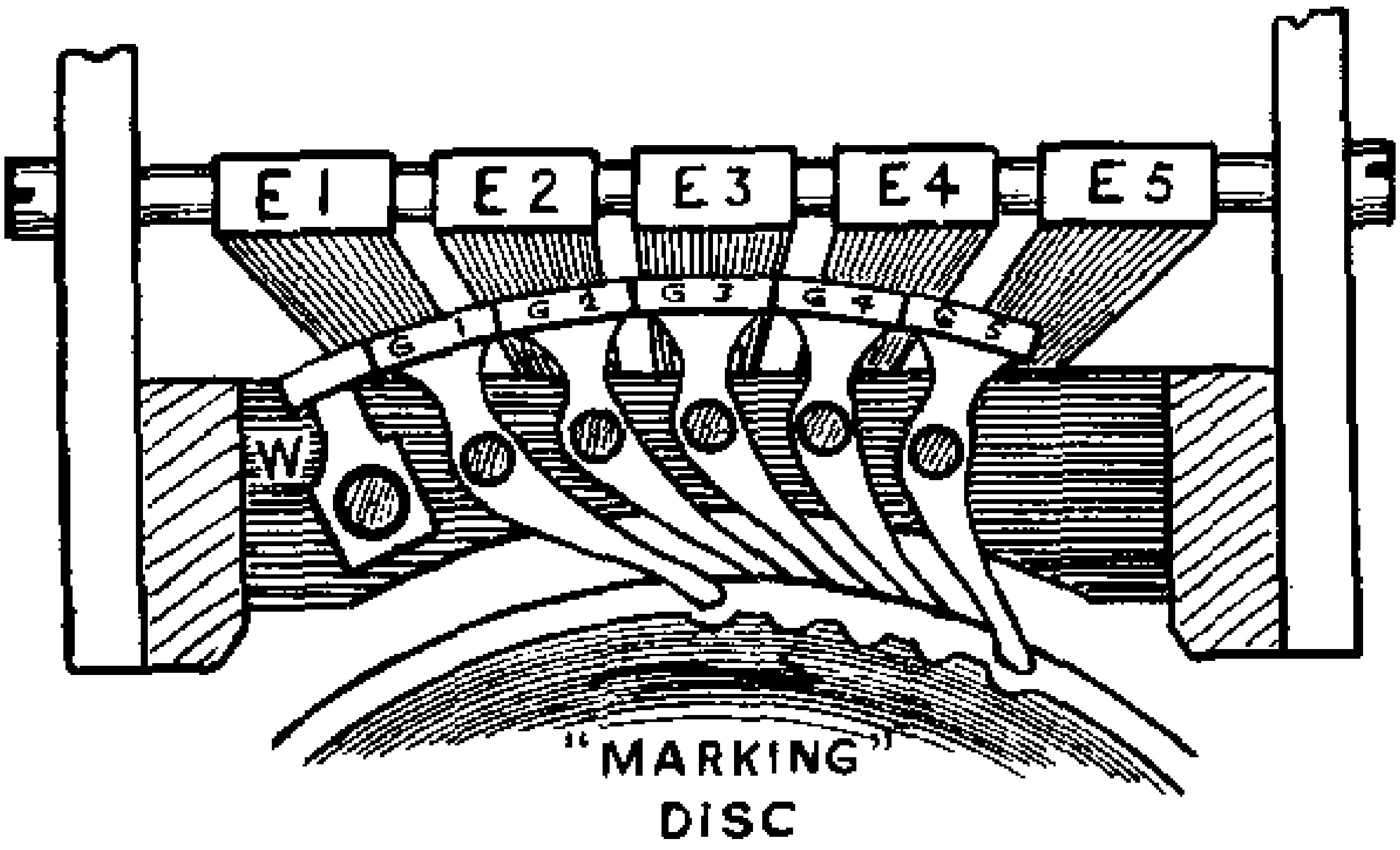


Fig. 119.—Receiver : details.

On the left of K is an incomplete ring, L. In the region of the break in this is a double cam, P R, the portion P being continued by means of a steel plate T. As the combiner revolves, T passes on the right of the vertical arm of E. If, however, the electro-magnet had been actuated, this arm would be forced, by the action of the spring F, to butt against the back of L. When T reaches E, in this case, the latter is kept on the right of the plate. On the arrival of the cut-away portion of L, the spring F and cam P cause the vertical arm to complete its movement to the right, and thus push forward its corresponding sliding lever into the marking groove, which is now open by the lower side of Q. The lever E, having done its work, now encounters cam R, which restores it to its normal position as in the figure.

The function of L, with the cam P R and plate T, is thus to allow in turn any or all of the levers E, which may have been actuated by their electro-magnets, to do their work of forcing over the sliding levers G. This done, they are restored to their normal position. The sliding levers thus pushed over are then in the marking groove.

We have seen that the depression of certain keys on the sender constitutes a letter. For instance, the letter K is represented by the depression of keys 1, 4, and 5. This results in the sending out of one marking, two spacing, and two marking currents. At the receiving end the electro-magnets 1, 4, and 5 are actuated, and their levers E butt against L. When T arrives it passes between this set of three levers on its right and the set of two unmoved levers on its left. The three arms of E 1, E 4, and E 5 then force the sliding levers G 1, G 4, and G 5 into the marking groove, the other two—G 2 and G 3—remaining in the *spacing groove*. We thus form in the receiver an exact counterpart of the combination made by the sender. We now have to see how this combination in the receiver is translated so as to cause the letter K to be printed.

The bases S and M of the spacing and marking grooves are notched on their peripheries. The notching extends over $\frac{35}{40}$ of the circumference, the rest being plain. The notching is seen in columns 9 and 10 of Fig. 113. Wherever a notch is cut in one disc the other is left plain.

Suppose that the letter A has been signalled on the keyboard by the depression of key 1. One marking and four spacing currents pass to line. In the receiver, No. 1 electro-magnet will respond, and G 1 will pass to the marking groove. Now, consider the first five notches on the top of the columns in Fig. 113. Reading these from the lowest of the five, so that the top notch is the fifth, we have No. 1 in the marking and the rest in the spacing groove. This corresponds with the combination of the keys representing A. There is thus a notch beneath the foot of every one of the five levers G. Under these conditions the spring U, acting on all their heads by means of W, forces them to the right and their feet into the notches. But the combiner is revolving at a fair speed, and the feet of the levers are no sooner in the notches than the travelling of the wheel throws them out. This ejectment is in the nature of a sharp tap or blow, and the levers are smartly thrown out of the notches. This blow to their feet is transmitted by their heads to that of the sixth lever, and the result is that the arm V attached to this has its free end thrown up. This raising of the arm allows the paper to be brought into contact with the type-wheel, of which the initial letter is A. A is, therefore, printed on the slip.

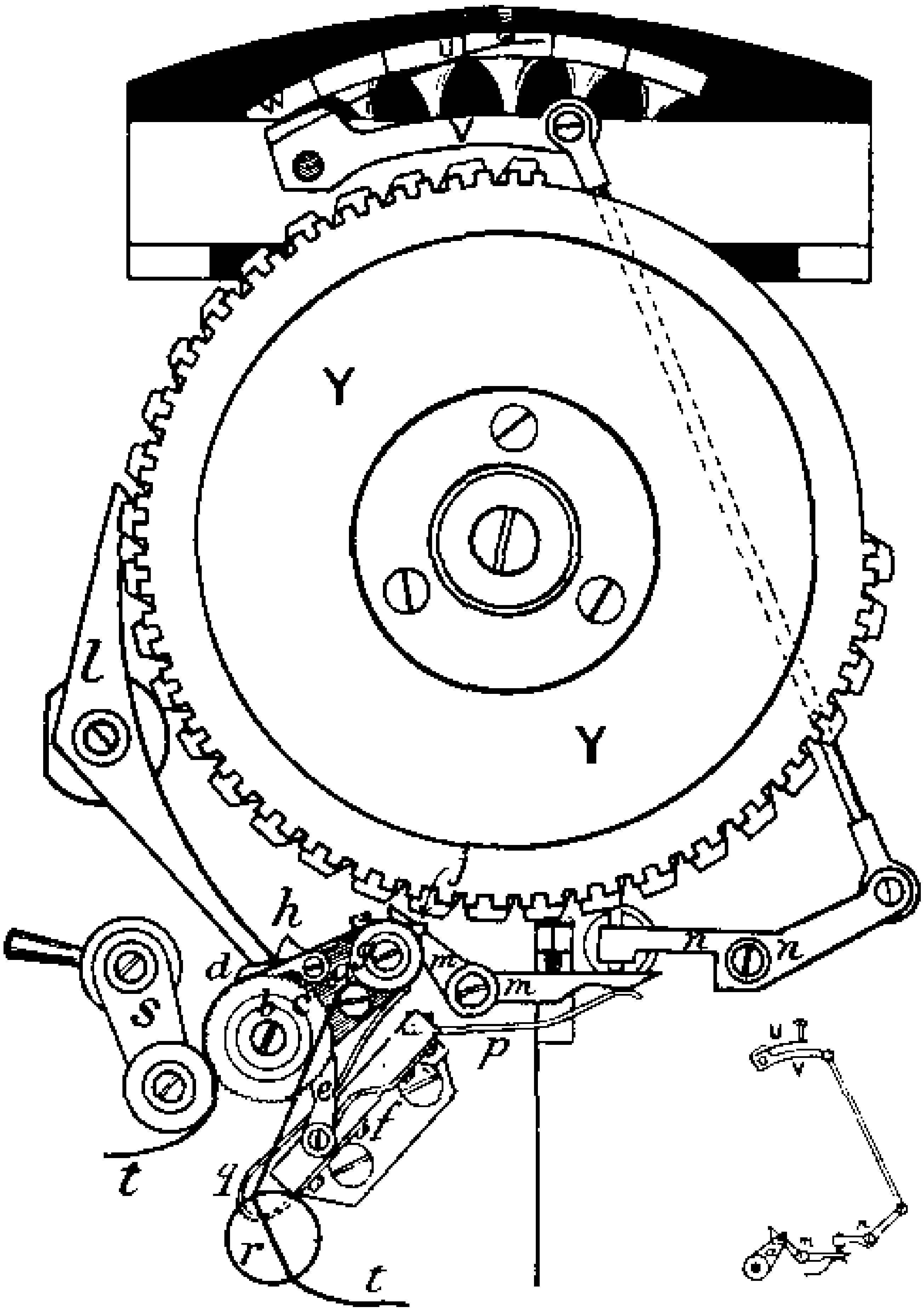


Fig. 120.—Receiver: printing mechanism.

If we move downwards another notch in the columns of Fig. 113, and make this the first of a fresh combination of five, we have the letter E. Moving a notch at a time, the last four of the preceding combination are used to form, with a new one, the five notches of the next.

Printing Mechanism.—On the outside of the receiver (Fig. 117) the axle J carries a toothed-wheel X, the type-wheel

Y, and the means by which they share the rotation of the axle. X has 31 teeth, occupying $\frac{31}{40}$ of its circumference, the remaining $\frac{9}{40}$ being plain.

The type-wheel, likewise, has $\frac{9}{40}$ of its circumference plain. Between the letters are figures and other signs, as given in Fig. 113. The letter series and figure series are brought into use by a device similar to that on the Hughes instrument.

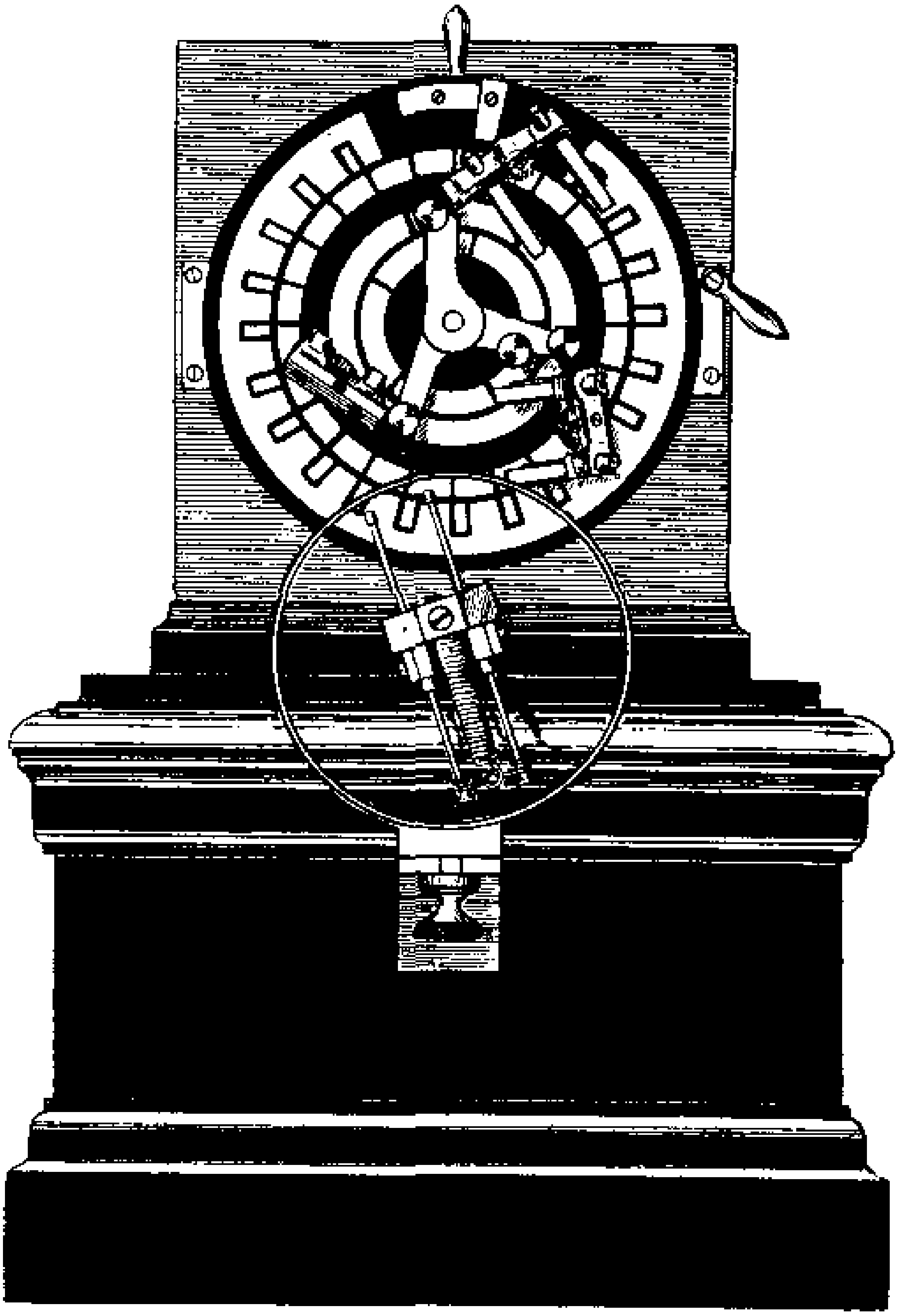


Fig. 121.—Distributor: front view.

In Fig. 120 *a* is the printing arm, movable on the axis *b*. Over this same centre is a cylinder, *c*, to which is attached a ratchet-wheel engaging with two clicks, *d* and *e*, by which the paper slip is propelled forward. At the back of the arm is the cam of entrainment, a piece of hard steel which forms a projection *h* and a pointed or sharp-edged end, *j*. Near this end a steel pin projects backward from the cam and engages with the hooked end of the hanging lever *m*, the right arm of which rests beneath an adjusting screw. Above this latter arm is the left-hand end of the lever *n*, whose other end is connected by means of a rod to the free end of the releasing lever V.

The lever *m* is normally held in the position shown by the spring *p*, its left-hand portion engaging with the pin at the back of the printing arm *a*. The latter, under the tension of spring *q*, tends to move to the left. If the movement were allowed (by releasing the arm from *m*), the pointed end *j* would enter the space between two teeth of X, and the two would move together until *j* were clear of X. As *a* and the wheel X move together, the paper, carried on the cylinder *g*, is brought into contact with

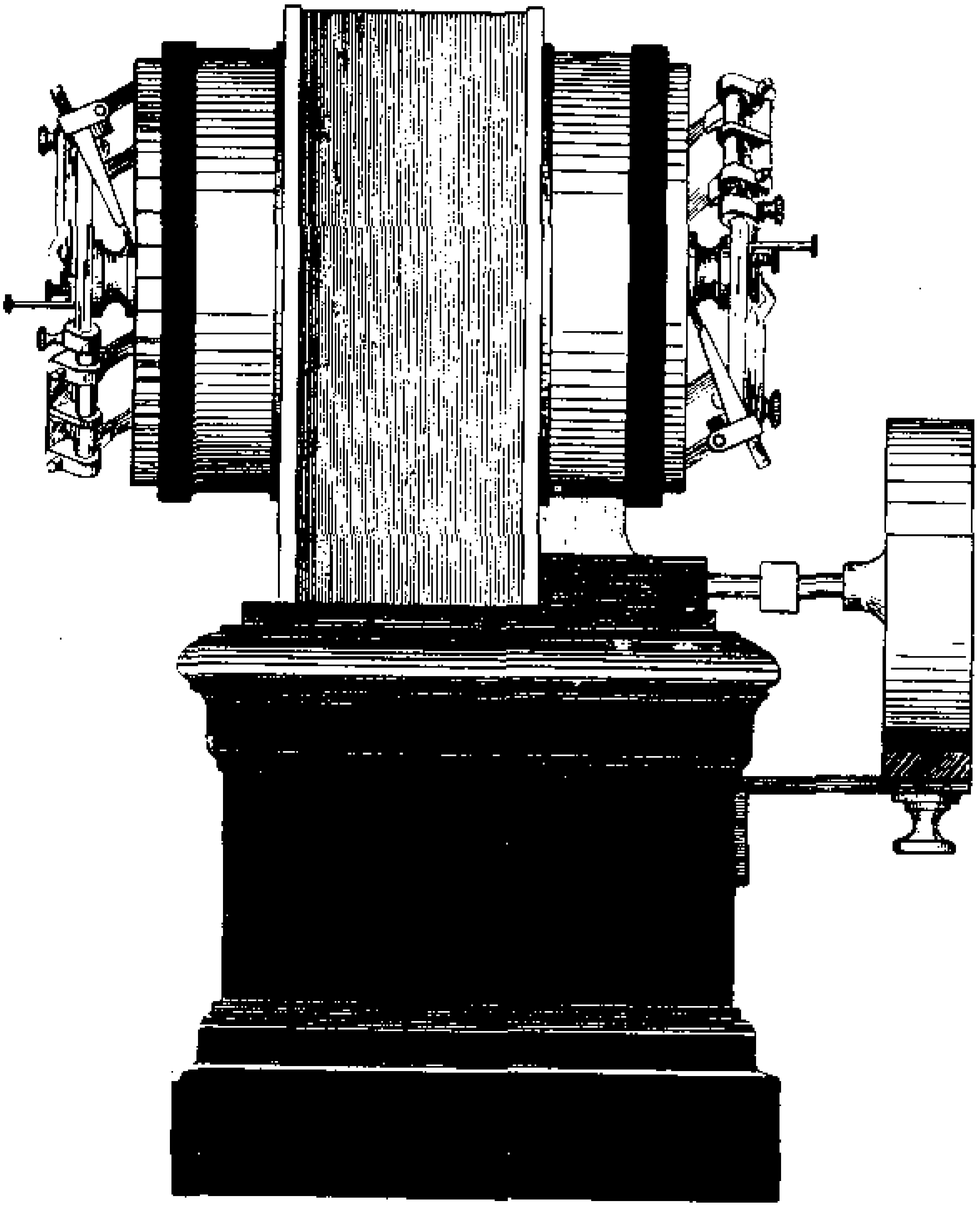


Fig. 122.—Distributor: side view.

a letter of the inked type-wheel and the printing accomplished. The pointed end *j* then passes clear of X, over to the left, the projection *h* pushing the lever *l* before it. The upper end of *l* therefore moves to the right, just behind the toothed-wheel. As X turns farther round, a projecting roller, *k* (Fig. 117), catches the upper part of *l*, and forces it outwards. The lower end of *l*, butting on the projection *h*, then pushes the printing arm back to its old position, the pin raising *m* slightly until it slips under the catch.

Distributor.—A front view is given in Fig. 121, and a side in Fig. 122. The segments, forming concentric rings, are mounted vertically on two ebonite plates fitted on the back and front of the case. Full details of the segments are given in Fig. 125, but their relationship can better be seen from the "straight" diagram of Fig. 123.

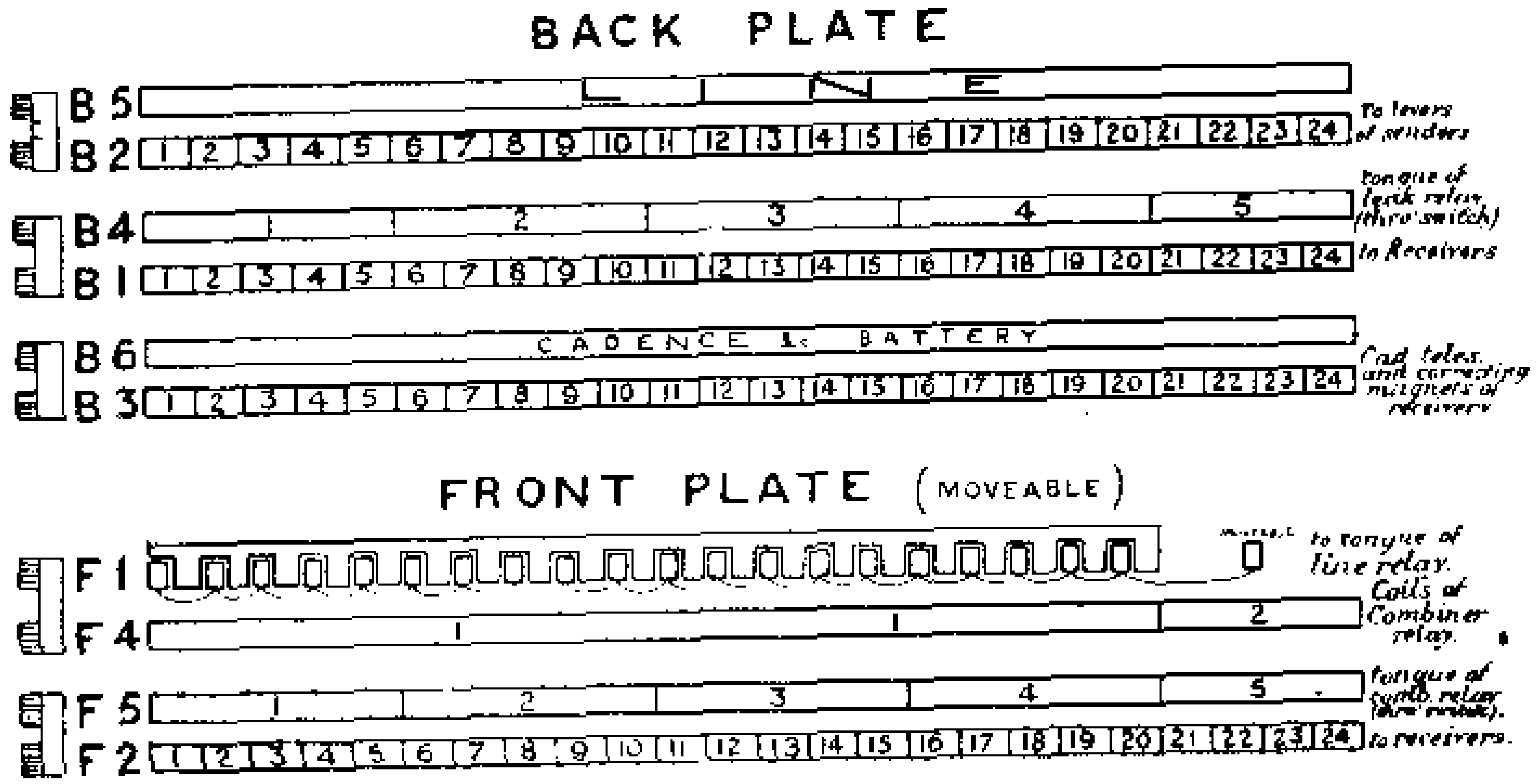
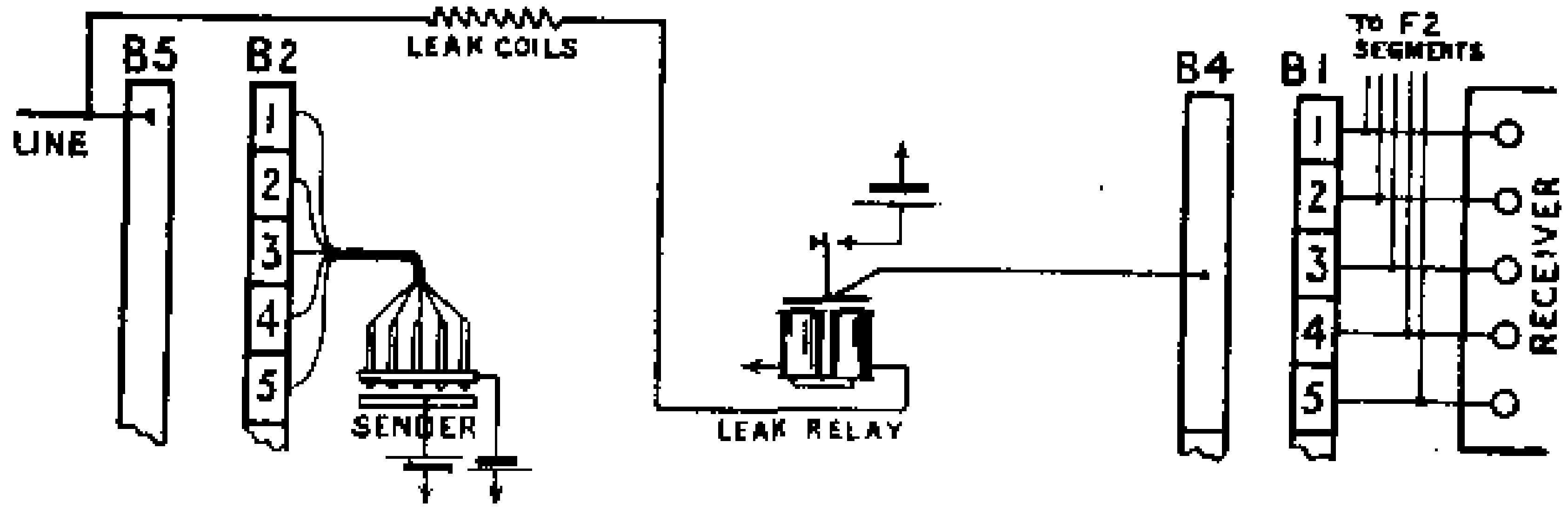
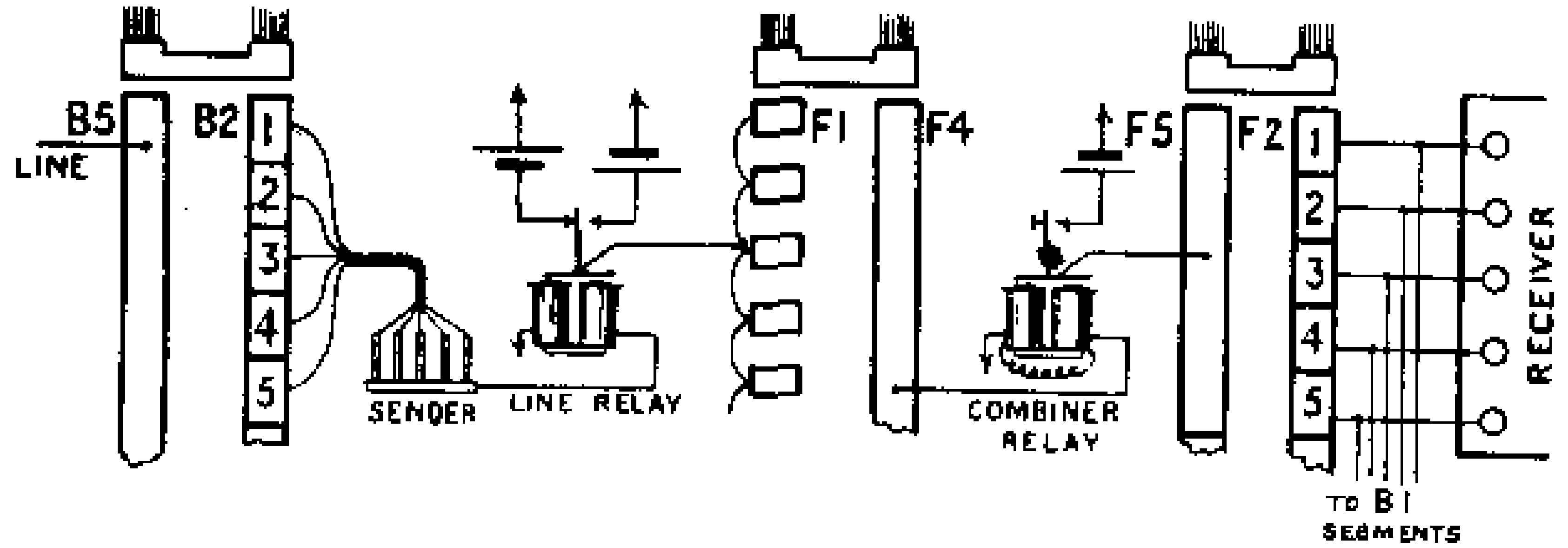


Fig. 123.

Connections of an Arm.—Fig. 124 gives the essential parts of a single arm for sending, and of another for receiving. In the former the spacing battery of the sender is brought to all the keys from terminal *c* by the upper right-hand contact of the switch. The levers of the keys are permanently connected to one set of five segments in ring B 2; hence, whenever the brush passes connecting B 2 with B 5—which latter is joined to line—five currents pass out. To B 5 is also brought one end of the high resistance leak coil, the other end being connected to the coils of the leak relay. Every current sent to B 2 segments therefore divides, the major portion going to the line, and a smaller passing through the leak relay. The latter has a battery on its marking contact, and its tongue therefore repeats these signals to one of the long segments of B 4, and by means of the brush connecting B 4 with B 1, to the electromagnets of the receiver on this particular arm. Thus a portion of the sent-out currents actuate the sender's own receiver by means of the local battery. This is to give the sending operator a check upon his own sending—as in the Hughes' system. The tongue of the leak relay is brought to B 4 by the switch which connects terminals *d* and *f* of the sender.



SENDING



RECEIVING

Fig. 124.—Connections of an arm.

The lower diagram of Fig. 124 shows an arm receiving. The spacing battery is cut off from the keys by the new position of the switch. and the keys are joined through *via* terminal *b* to the coils of the line relay. To the marking and spacing contacts of the latter are connected the positive and negative poles of two local batteries. The received currents passing from B 5 to B 2 traverse the keys, and pass to earth through the line relay coils. The tongue of this instrument sends (double-current) to the shortened segments of F 1, and by the brush to the long segment of F 4, and thence to the coils of the combiner relay. The latter, in its turn, sends single-current (marking) by the local

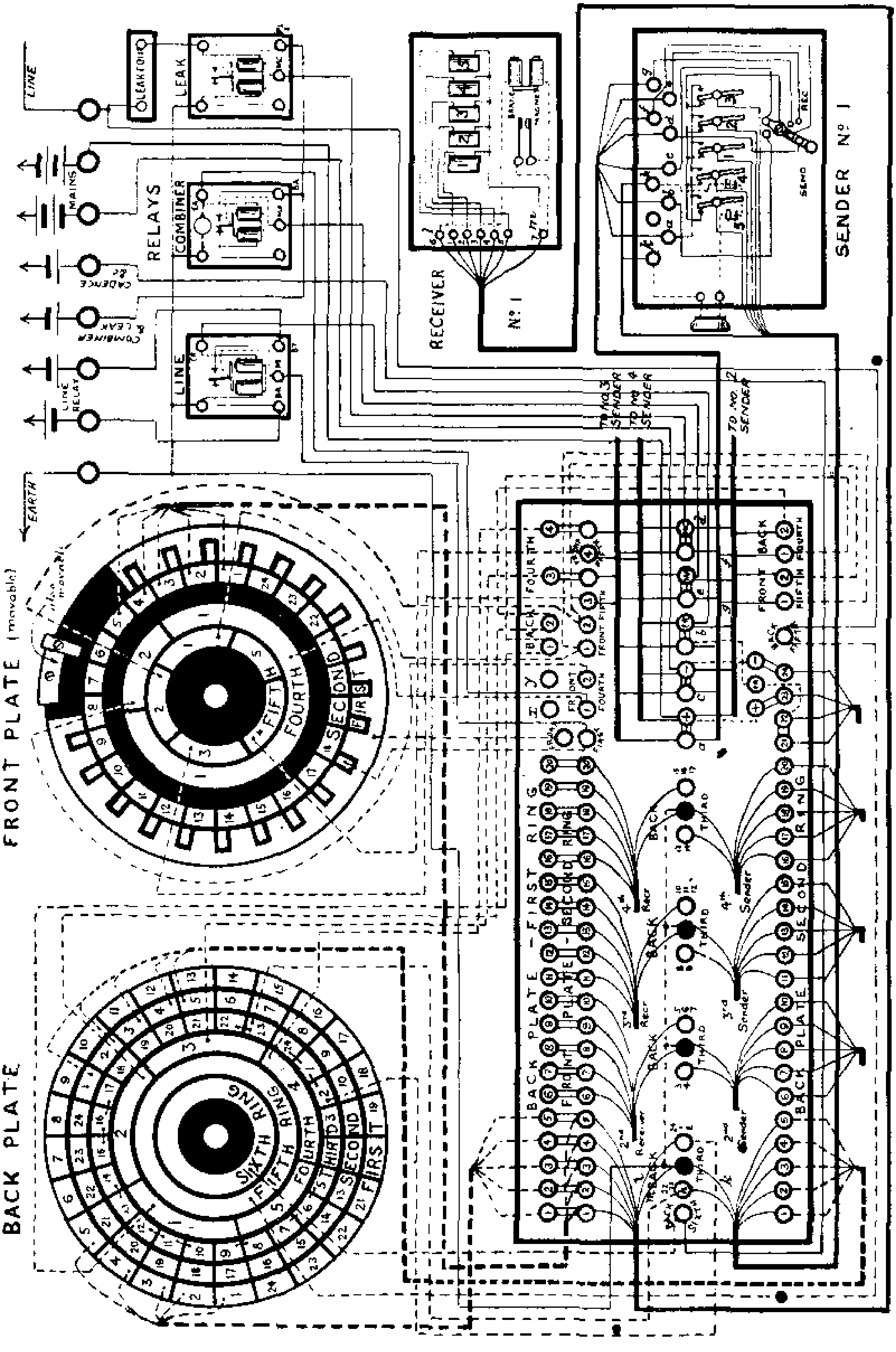


Fig. 125.—Baudot: tetrode working.

battery on its marking contact to one of the long segments of F 5 by terminals *c* and *g* of sender, and across the brush to the receiver. The latter is connected both to the segments of F 2 and B 1. The front plate, it will be seen, is entirely occupied with the receiving portions of the apparatus.

The received signals arrive, not sharply divided into their constituent impulses, but as a series of "waves" more or less running into each other. The shortened segments of F 1 serve to separate them, and to utilise the "crests" or best portions of these waves. The combiner relay is fitted with a low resistance shunt—thus rendering its movement sluggish. The signals are thus repeated into the receivers at their proper length.

Synchronism.—The electrical synchronising arrangements are really two, main and local. For the first the distributor at the correcting station is made the standard, and sends correcting currents regularly to line. At the corrected station the distributor is fitted with apparatus to be actuated by these currents. The latter distributor is set to run slightly ahead of the other, and the correction acts in a retarding sense.

Each distributor also controls its own receivers, sending a correcting current to each in a single revolution. The receivers are set to run slightly fast, and the correcting current causes a brake to be applied, thus damping down the speed.

As in the case of the Hughes, isochronism rather than synchronism obtains. At both stations the line is brought to the segments of B 2, and both sent and received currents pass through the levers of the senders. In the case of each distributor and its receivers it is easily seen that each of the latter must be in different phase to its neighbour.

Diagram of Connections.—Fig. 125 gives the connections of a tetrode set. The dotted lines indicate the interior connections of the distributor—that is, from the segments to the terminals shown in the lower rectangular figure. Where "cables" are shown, either dotted or full, both ends are numbered, thus avoiding a large number of single connections and greater complexity. Only one sender and one receiver are shown, but the others are joined up in precisely the same manner.

For an ampler and more fully detailed description of the systems considered in this and in the preceding chapter, the reader is referred to the author's *The Hughes and Baudot Telegraphs.*

CHAPTER IX.

THE MURRAY TYPE-PRINTING TELEGRAPH.

In this system the only skill employed is that of a typist at the sending end. This operator, who need not be a telegraphist, types the messages on an ordinary keyboard, but instead of appearing in the usual characters on a form, the message comes out in arbitrary signs on a perforated slip. Here the skill ends: all the rest being electrical and mechanical. The prepared slip is passed through a species of Wheatstone transmitter, which sends, in

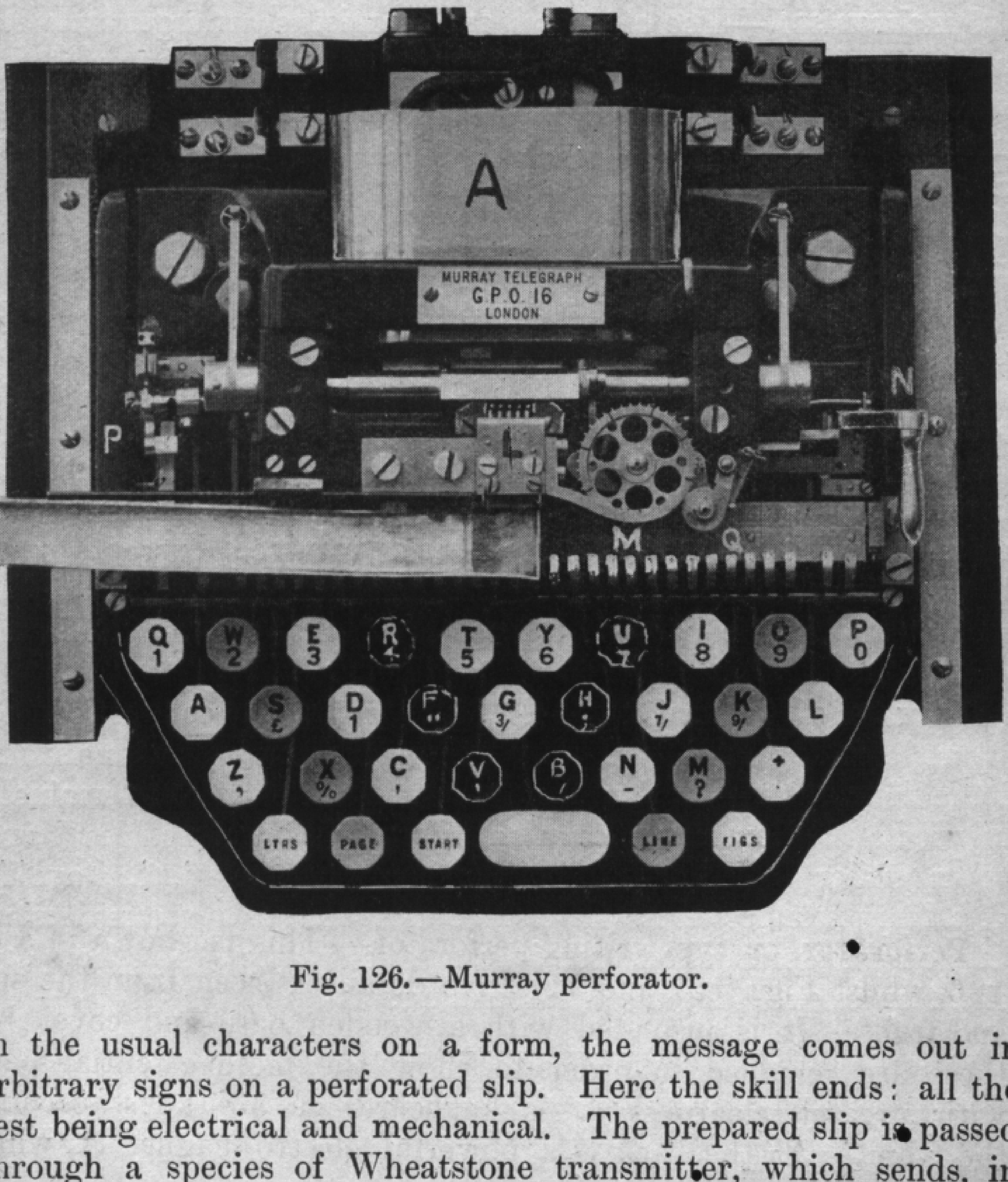


Fig. 126.—Murray perforator.

obedience to the perforations in the former, currents of varying length and direction. At the receiving end, these signals cause a similar slip to be perforated. This slip, in its turn, being passed through (at leisure) an attachment to a typewriter, actuates the keys of the latter, and the message is automatically typed on a form.

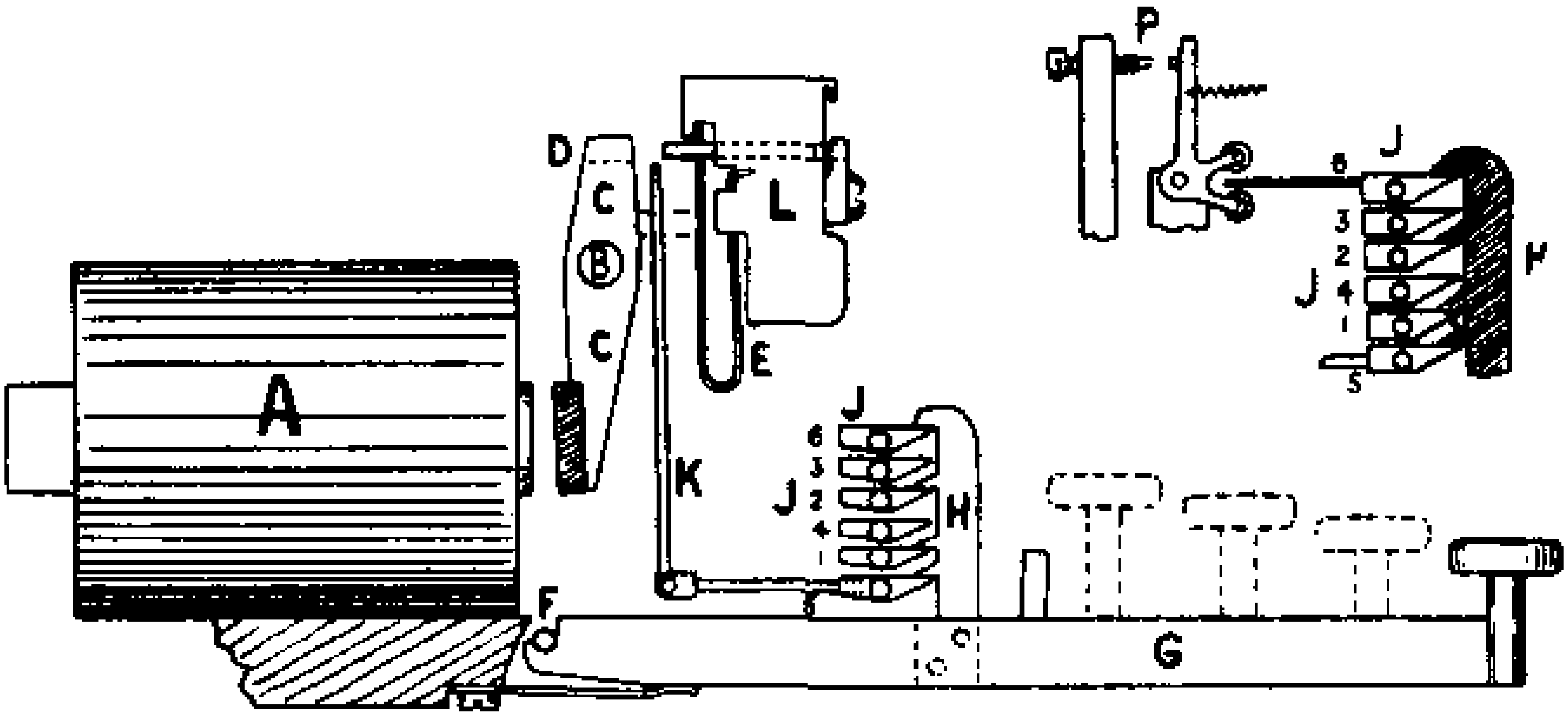


Fig. 127.

These operations naturally fall into three divisions—(*a*) the typing with its resulting perforated tape; (*b*) the electrical transmission over the line and through the receiving apparatus, resulting in the second perforated tape; and (*c*) the rendition of the signals on the latter into ordinary typewritten characters.

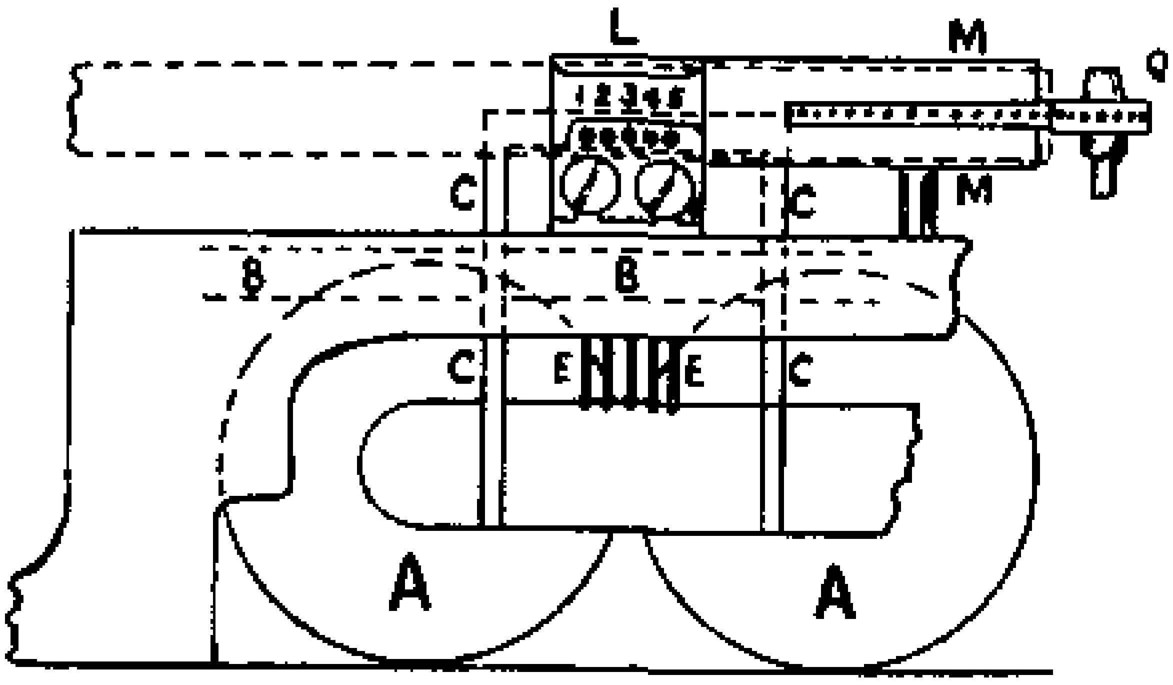


Fig. 128.

Perforator, or typewriting perforator.—This is shown in Fig. 126, whilst Figs. 127 and 128 give details as seen from the side and front. It is provided with a wooden base and cover, but these are removed in order to show the more essential parts with greater clearness. A keyboard of 33 keys occupies the front. At the back is a powerful electro-magnet, A, which is energised whenever a key is struck. A is enclosed within a thin metallic case, presenting the appearance shown in Fig. 126. An axle, B, runs across the back of the keyboard, being carried in two bearings. At each end is an arm, to the extremity of which is fastened a strong spiral spring, keeping the axle in a certain position. On this axle is a frame, C, carrying at its lower part the armature of the electro-magnet, and at its upper part a bar D. This bar is normally kept drawn backwards, and the armature off the electro-magnet poles, by the tension of the spiral springs before-mentioned. Immediately in front of D is the punch-block L, in which is a horizontal row of five punches, *normally* drawn backwards by five **U**-shaped springs E. Whenever a key is depressed the electro-magnet attracts the armature and the bar D moves forward, tending to strike the punches forward. Its travel, however, is not quite sufficient to enable it to reach them.

Each of the keys G is pivoted at F, and is kept up by the pressure of a flat spring. Each key carries a vertical arm, H, whose back edge is furnished with one to six hooks or catches, and immediately behind the series of arms is a set of six stout steel strips, J, pivoted as shown in Fig. 127. On the back edge of each strip, J, is a horizontal arm, to which is connected an upright rod, K. Only one of these is shown. The upper end of K is flattened, and normally rests just below and at the back of the punches. When, therefore, any key is put down, the hooks on its vertical arm H will depress the forward edge of one or *more of the strips J. The back edge will rise* and push up its rod K, so that the end is between the bar D and one of the punches. This action takes place at the initial stage of the downward movement of the key. The completion of the movement closes the circuit of the electro-magnet, the bar D moves forward, and by means of the ends of any rods, K, which have been raised, is enabled to strike the required punches and perforate the slip.

The hooks on the arms H are different in number and position for each key, excepting that all actuate the top strip 6, whose function is to close the contact P of the electro-magnet seen separately on the right of Fig. 127. This strip, therefore, has no rod, K. The others are arranged to raise one, two &c., or all of the remaining five strips, and thus enable the striker bar D to actuate any desired punch or group of punches.

To the right of the punch-block L in Figs. 126 and 128 is the star- or feed-wheel M, whose normal function is to feed the slip forward. This is urged round in a clockwise direction one letter space (5 units) by the return of the armature system after striking the punches. It will be seen that M is marked off into eight complete spaces, each of which contains five teeth. The slip is similarly marked, and on inserting the end of a roll care has to be taken that the marks on the slip and those on the wheel correspond.

On the right of M (Fig. 126) is an arm, N, which, on being pushed to the left, causes the star-wheel to rotate one letter space in the reverse direction to its ordinary movement, and it thus brings back the slip one letter. This is for use when a letter or word has been wrongly punched. Without this device the error, although indicated later, would be printed on the message form at the receiving end along with the correction. By means of this device, however, the paper is drawn back, one letter for each movement of N, to the required extent, and the "letters" signal punched repeatedly. This causes all the punches to be operated, and each space on the slip is thus perforated with five holes—that is, whatever spaces were left in the previous operation are now punched with holes, entirely obliterating the former characters. At the receiving end, as we shall see, this causes no record whatever to be made, so that, in the finished message, no trace of the error appears.

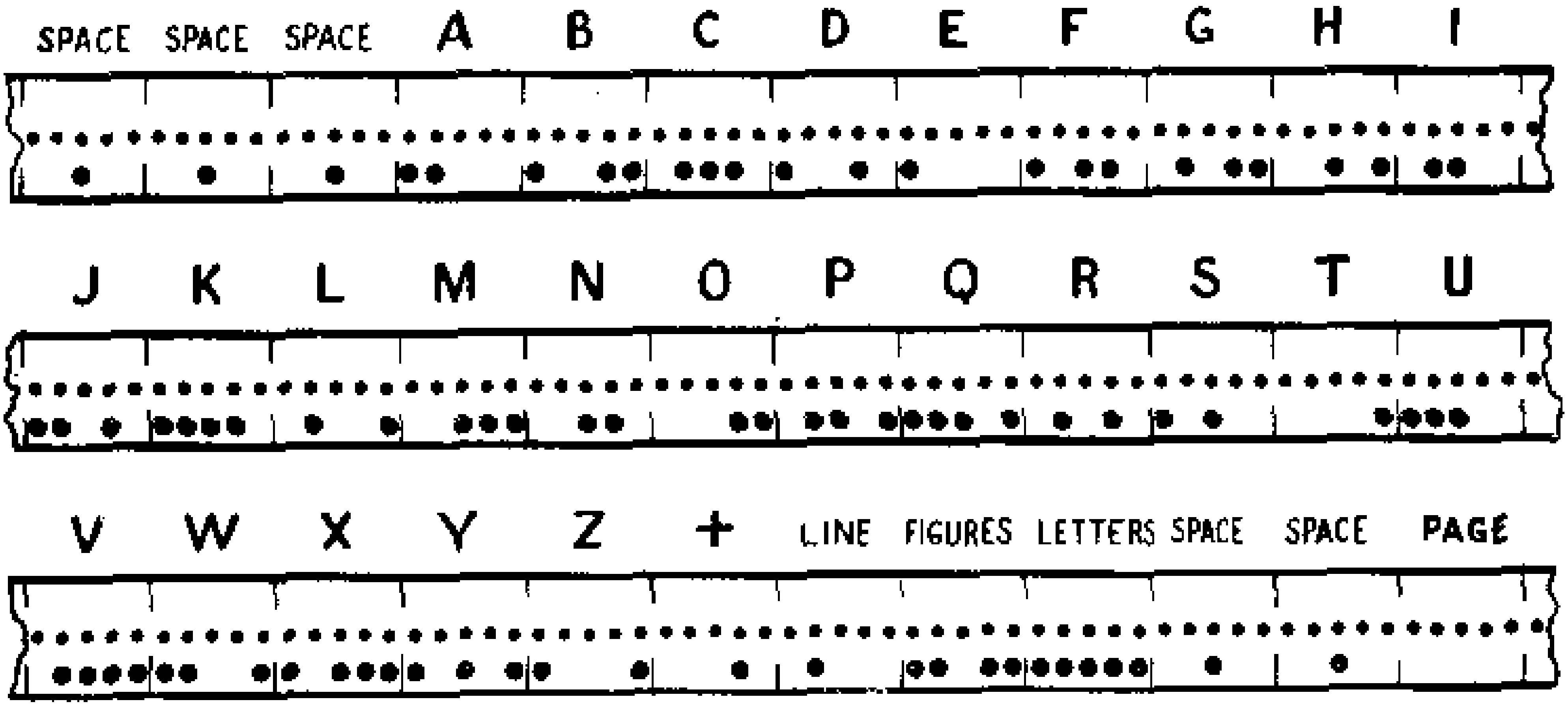


Fig. 129.—Murray alphabet.

Murray Alphabet.—Like the Baudot, this is an equal-letter 5-unit alphabet. The slip, before insertion in the perforator, has been centre-holed and marked, as shown in Fig. 129. Each of these divisions has thus five positions, and is occupied by a single letter. The depression of the key "E" tilts strip J, No. 1, and causes No. 1 punch to perforate the strip with a hole in the first position of one division of the tape. The depression of the "space" key actuates strip 3, and causes a hole to be punched in the third position of another division. The key labelled "letters," if depressed, causes five holes to be punched, and so on.

With a 5-unit alphabet 31 combinations are possible. These are appropriated as follows:—26 for the alphabet, the sign +, the "space" signal (between words), and the "line" signal = 29.

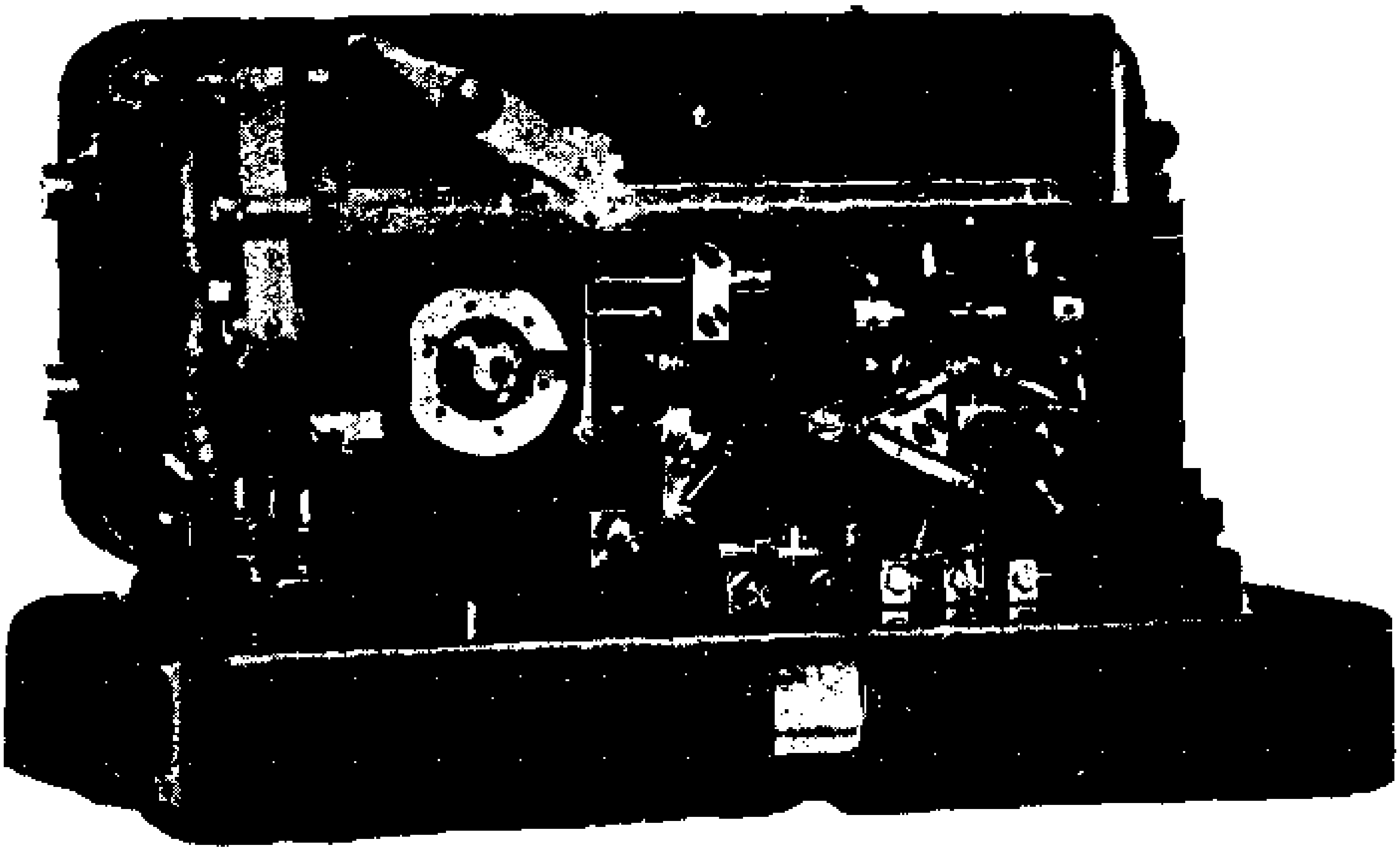


Fig. 130.—Transmitter: front.

But it will be seen that, in addition to a letter, each key carries a figure or a sign. It is, therefore, arranged that, by prefixing a suitable signal, all the above 29 shall indicate a new series of figures and signs. This signal is punched by the key labelled "figures," and, to bring back the letter series, another signal is punched by the depression of the key marked "letters." Thus, for 29 signs, we obtain 58 characters.

With an ordinary typewriter, when the end of a line is approaching, a warning bell rings. This is also arranged for, and, as the receiving apparatus is required to start a fresh line at the proper place, the "line" key is depressed to effect this.

The key marked "page" does not actuate any of the punches, but energises the electro-magnet as usual, and thus feeds the paper forward. At the receiving end it serves as a stop signal.

Transmitter.—The slip having been prepared, we have to consider the transmitter. This, known as the "single-line" instrument, because only a single row of (signalling) holes is punched on the slip, is shown in Figs. 130, 131, and 132. The first is a front view, the second a back view, showing the motor, and the third a diagram of the instrument.

An upright arm, A, is mounted on a pin, G. Its upper end is connected by a rod to the disc D, carried on an axle which protrudes through the front of the instrument, and which is kept constantly rotating in the direction shown. Its rate is such that it makes five revolutions for each letter on the slip, or one per unit. The upper end of A, therefore, moves to the right and left alternately. Pivoted on A is a horizontal arm, B, whose left-hand end is connected to the rod C. A shoulder on B normally banks against a pin on A under the tension of a spiral spring connecting the two arms. If it be free to do so, the system A B will move as one. H is the contact lever moving between two stops, M and S. By reason of the pressure of the jockey-wheel J upon its lower edge, the lever cannot maintain an intermediate

Fig. 131.—Transmitter: back, showing motor.

position. Hence, when it is pushed over to one side, it remains there until it is thrust over to the other. F is a forked attachment by which it is moved by the arm B.

As A moves to the right, B necessarily shares the movement. If the rod C be free to rise (through a perforation in the slip) the right-hand end of B will not only move towards F, but also in a downward direction. It, therefore, butts against the end of the lower arm of F, which is slightly hollowed or concave. This forces H over to the marking contact. If the rod C encounters unpunched slip it cannot get through, and the end of B has an upward movement. With the lever in the position shown in Fig. 132, B will not quite reach the upper arm of F, as it is already in the position to which B would move it.

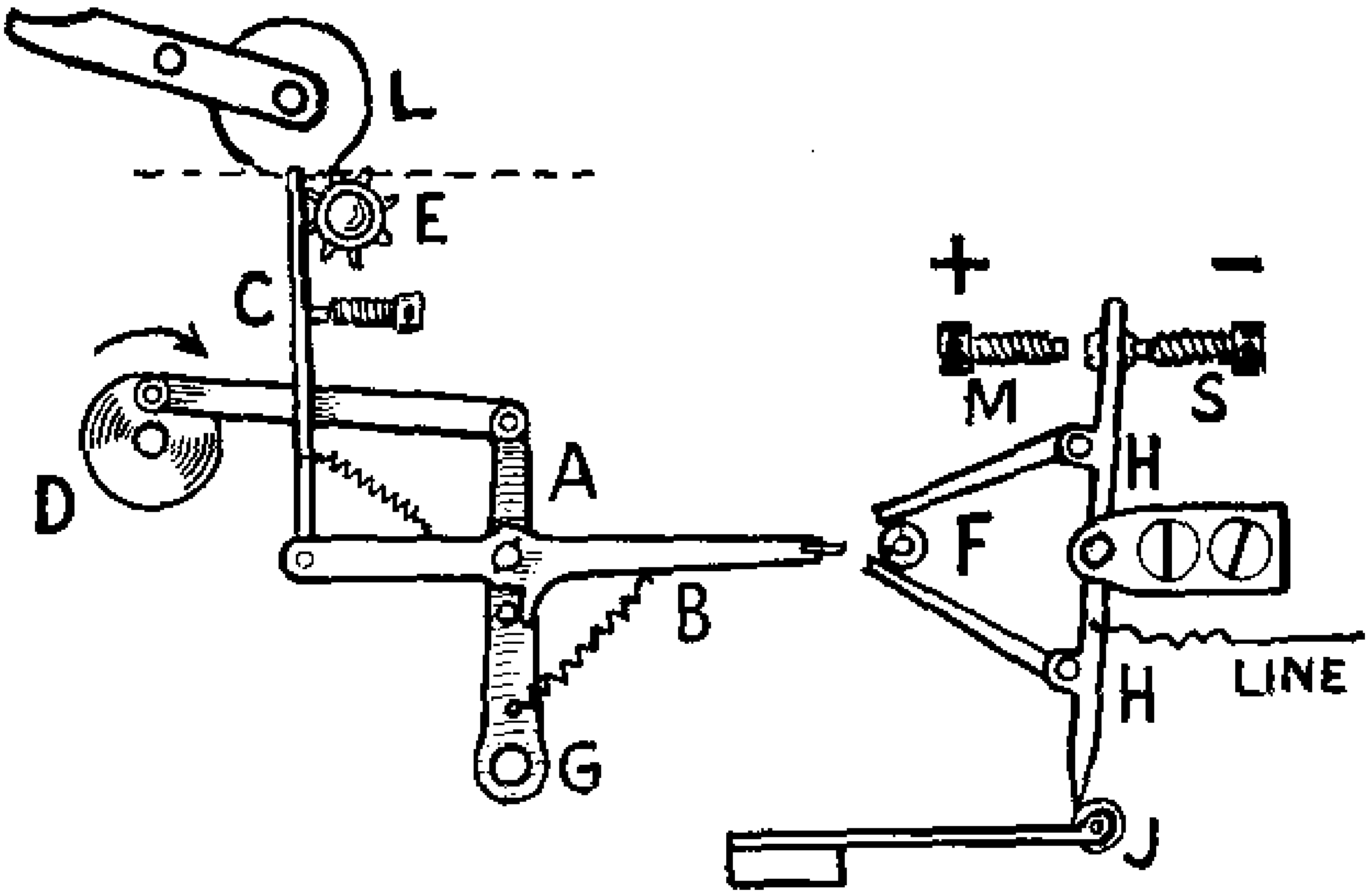


Fig. 132.

If the instrument were run without slip the rod C would ascend; H would be pushed over to marking in the first revolution of D, and would remain there. In order that reversals may be sent out when no slip is inserted, the wheel L, engaging with E, is capable of a slight forward movement by which it presents to the rod C a solid and a cut-away portion alternately, so as to allow the rod to rise at one revolution and to prevent it at the next. With L in its normal running position the wheel is cut away entirely in the path of C, so that the latter may rise whenever a perforation in the slip allows. If two perforations occur together, or two unperforated units, the lever simply remains over where it was last placed. The components of a letter, if of similar sign, thus run into each other, and similarly with adjacent letters.

Motor and Transmitting Vibrator (driving reed).—The transmitter is driven by a small synchronous motor—the "phonic wheel" of Chapter VI. This can be seen in the back view of the instrument in Fig. 131. The wheel has seven teeth and two electro-magnets. The intermittent currents for driving the wheel are sent from the "transmitting vibrator" of Fig. 133. This is a steel bar firmly clamped at one end and carrying an adjustable weight or "bob" at the other. It has a contact on either side which completes the circuit of the opposite electro-magnet and thus maintains the reed in vibration. Each of the motor magnets is in series with one of the reed magnets, so that the two latter are alternately excited by the movements of the reed. This is seen in Fig. 134.

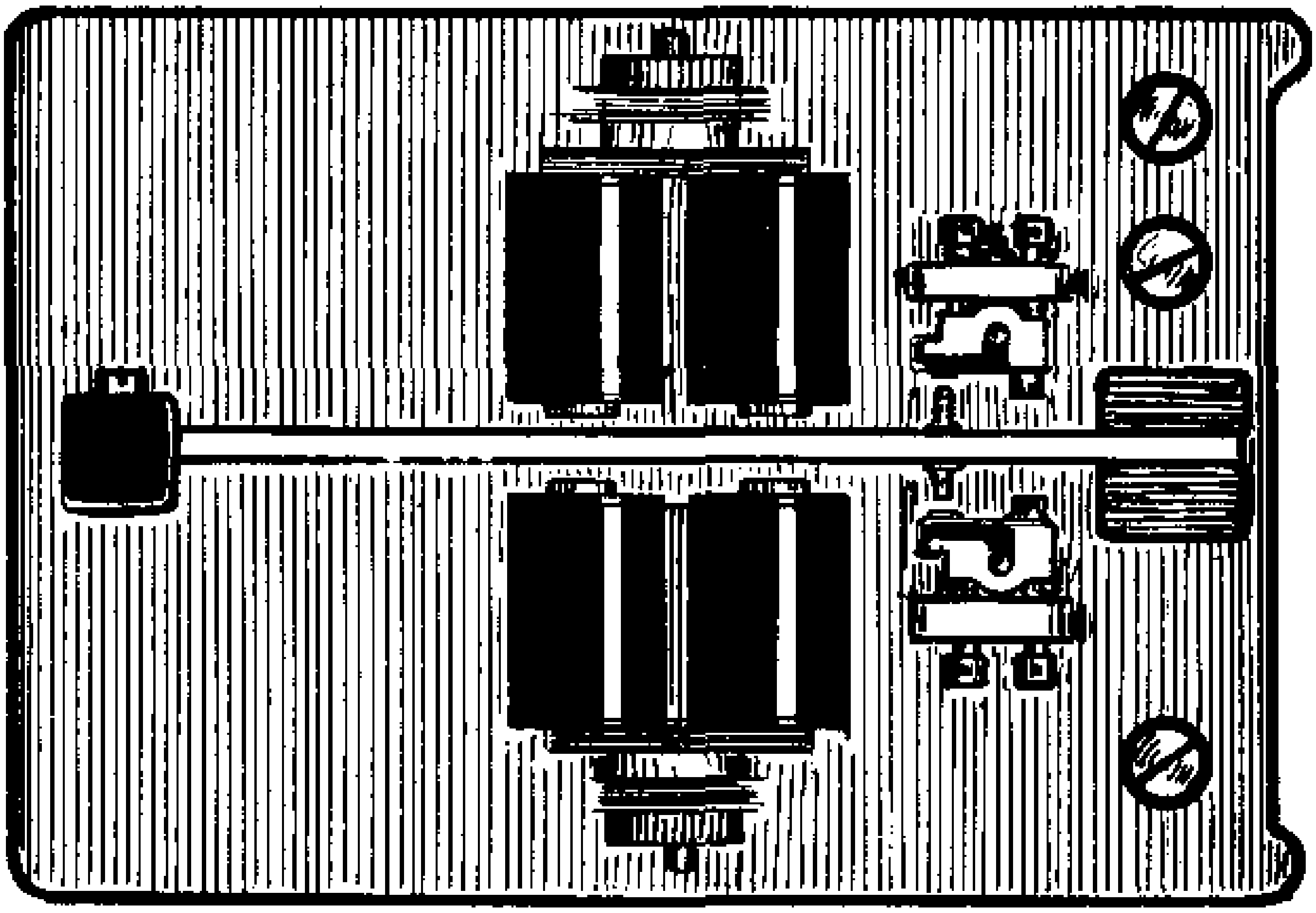


Fig. 133.—Transmitting vibrator.

Receiving Apparatus.—The line signals are received on an ordinary standard relay, and the receiving instruments are placed in the local circuit of this relay. We shall describe and illustrate the several instruments, but their functions can only be properly understood when we consider their concerted action.

Receiving Vibrator or reed.—This illustrated in Fig. 135 is similar to the driving reed of Fig. 133, excepting that it is provided with a pair of brass "buffer" springs, whose tendency

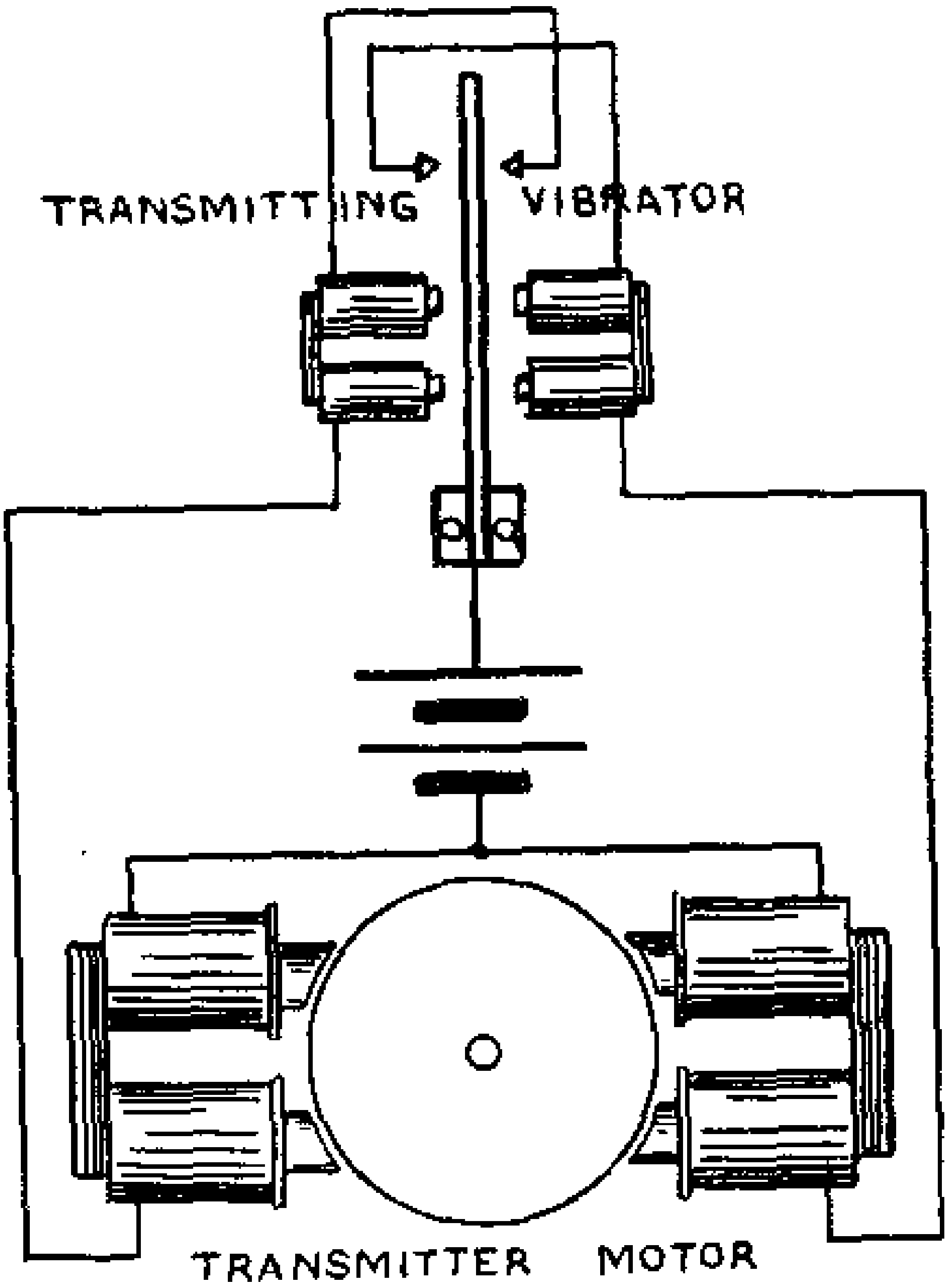


Fig. 134.

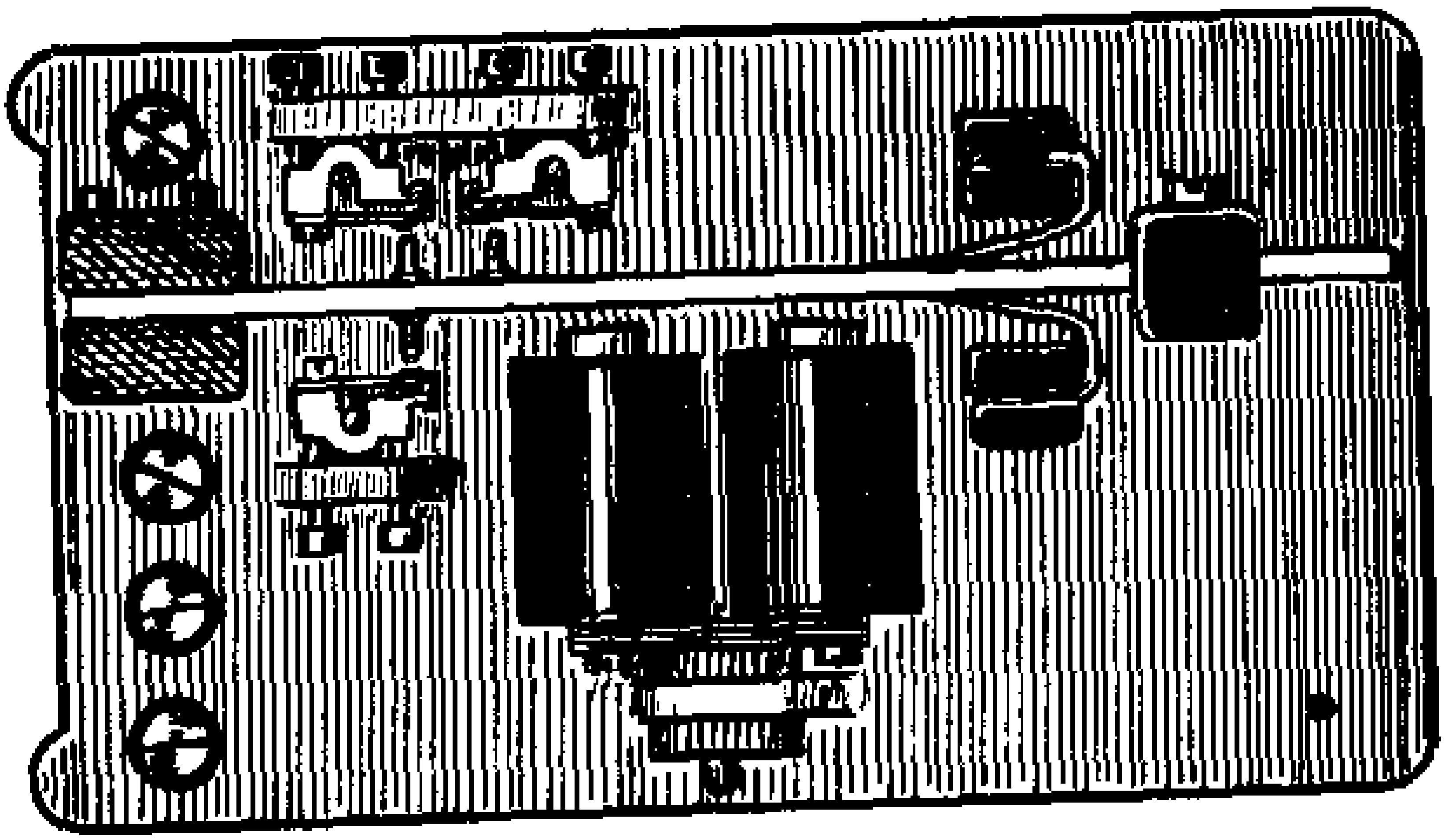


Fig. 135.—Receiving vibrator.

is to imprison the reed or to oppose its vibration. It is actuated by a single electro-magnet. For successful working it is necessar to maintain perfect accord between the sending and the receiving apparatus. The reed is adjusted to have a tendency to run slightly fast, whilst the action of the springs tends to retard its motion. When the acceleration reaches an appreciable amount it results in the shortening of the impulses given to the reed by its driving battery. The springs thus have a greater relative effect and check the acceleration.

Local Relays.—These are the punching relay and the governing relay, each a plain electro-magnet whose armature is held off the cores by a spiral spring. They are placed in series with each other and with a battery, in the local circuit of the receiving relay. Thus, whenever the tongue of the latter goes to marking, both relays are actuated. The punching relay has a single contact which is closed by the attraction of the armature. The governing relay armature has two contacts and these are connected together. The local circuit is thus complete, whether the armature is at rest or attracted, but is subject to short breaks whilst the armature is passing from one contact to the other. This break is the means by which the vibrations of the receiving reed are retarded or governed.

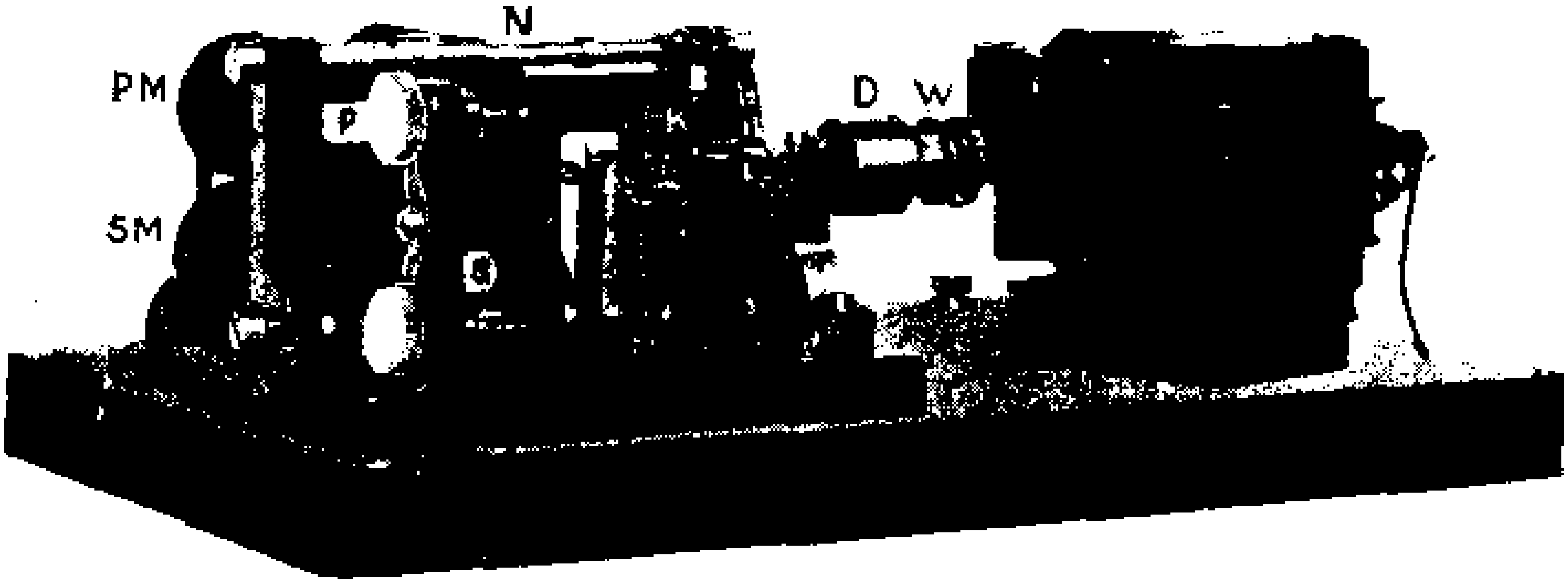


Fig. 136.—Murray recorder.

Recorder.—*This consists of the punching and spacing electro*-magnets, the punching mechanism, and an electric motor, mounted on a single base, as in Fig. 136. Fig. 137 is also a view of the two magnets and other parts as seen from the motor end of the recorder.

The punching magnet P M is placed above the spacing magnet S M, and its armature, P, is rigidly connected to the shaft N above it, the latter also carrying an arm at the end of which is the punch, moving in the punch-block K. When the armature P is attracted by the passage of a *momentary current through* the coils, the punch is driven downwards through the slip which passes in the horizontal space between the upper and lower portions of the block. The punch is withdrawn by a spring. The armature S of the spacing magnet is mounted in a similar manner on another shaft, R, below it. R also carries a two-armed pawl, V, engaging with a ratchet-wheel, Q. When S is attracted the pawl moves to the right, and between the disengaging of its right arm and the engaging of its left with Q the latter slips round a certain distance. When S is released Q slips round a further distance, and by these two motions the slip is fed forward. The movement is effected in the following manner:—The motor shaft terminates in a kind of metallic reel, W, which carries two flat springs, on the ends of which are two felt pads or brushes. In exact alignment with the motor shaft, but quite separate from it, is the shaft carrying the ratchet-wheel Q and a star-wheel by which the slip is propelled forward. This shaft carries a loose drum, D, the two being connected by a flat spiral spring which occupies a portion of the inner space of the drum. The two felt brushes carried by W engage with the inner surface of D with considerable friction. The drum shaft is held immovable by its ratchet-wheel Q, but the motor is continually running. The friction between the brushes and the drum is

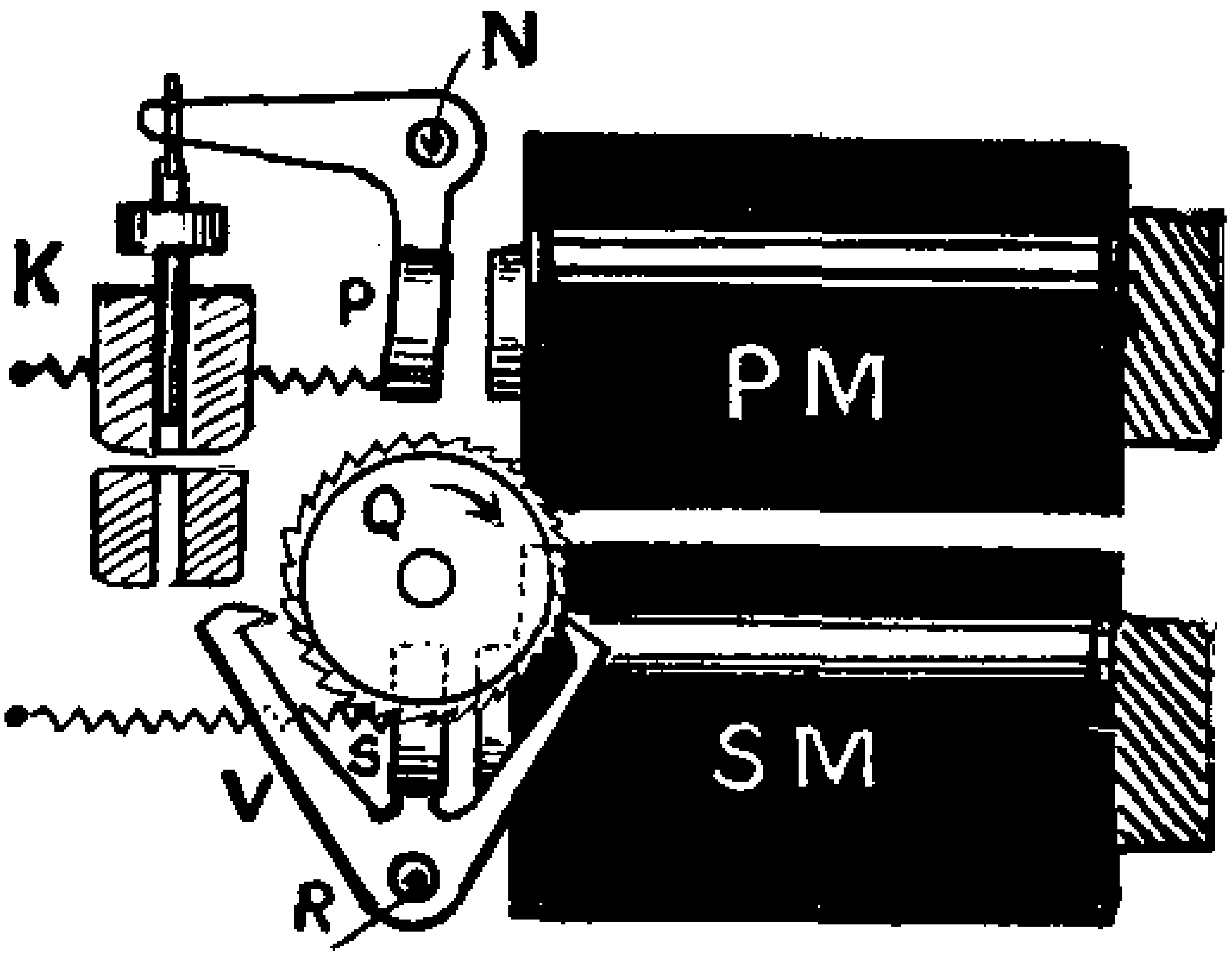


Fig. 137.—Recorder: details.

sufficient to carry D round with them, and thus to *wind up* the spiral spring. This goes on until it is quite wound up, when the brushes simply slip round inside D without moving it. When, now, the armature S moves either to or from the cores, and thus allows two short intervals of freedom to Q, the latter slips round under the tension of the wound-up spring. The sum of the movements due to the attraction and release of the armature is such as to give the slip a movement of one-fifth of a letter space. Thus, whenever the punching magnet is energised, a hole is punched in the slip, and when the spacing magnet is actuated the slip is advanced unit distance. The function of the motor is simply to keep the spiral spring wound up.

Concerted Action of Receiving Apparatus.—Fig. 138. shows the assemblage of the instruments we have just described. The reed R, with the battery X, is arranged so that a movement to one side completes the circuit of the spacing magnet. A movement to the other side, if the punching relay contact be closed, completes the circuit of the punching magnet. If the relay contact be kept closed, and the reed kept in vibration, the punching and spacing magnets will be actuated alternately, and the slip will be perforated and drawn forward—a perforation occurring opposite each hole of the central row of guide holes. The punching relay, however, is under the control of the receiving relay F. If the tongue of the latter be kept over to marking—say by the continuous current due to a succession of "letter" blanks—the recorder slip will be perforated, as we have already considered. If the tongue of F be to spacing, the punching relay

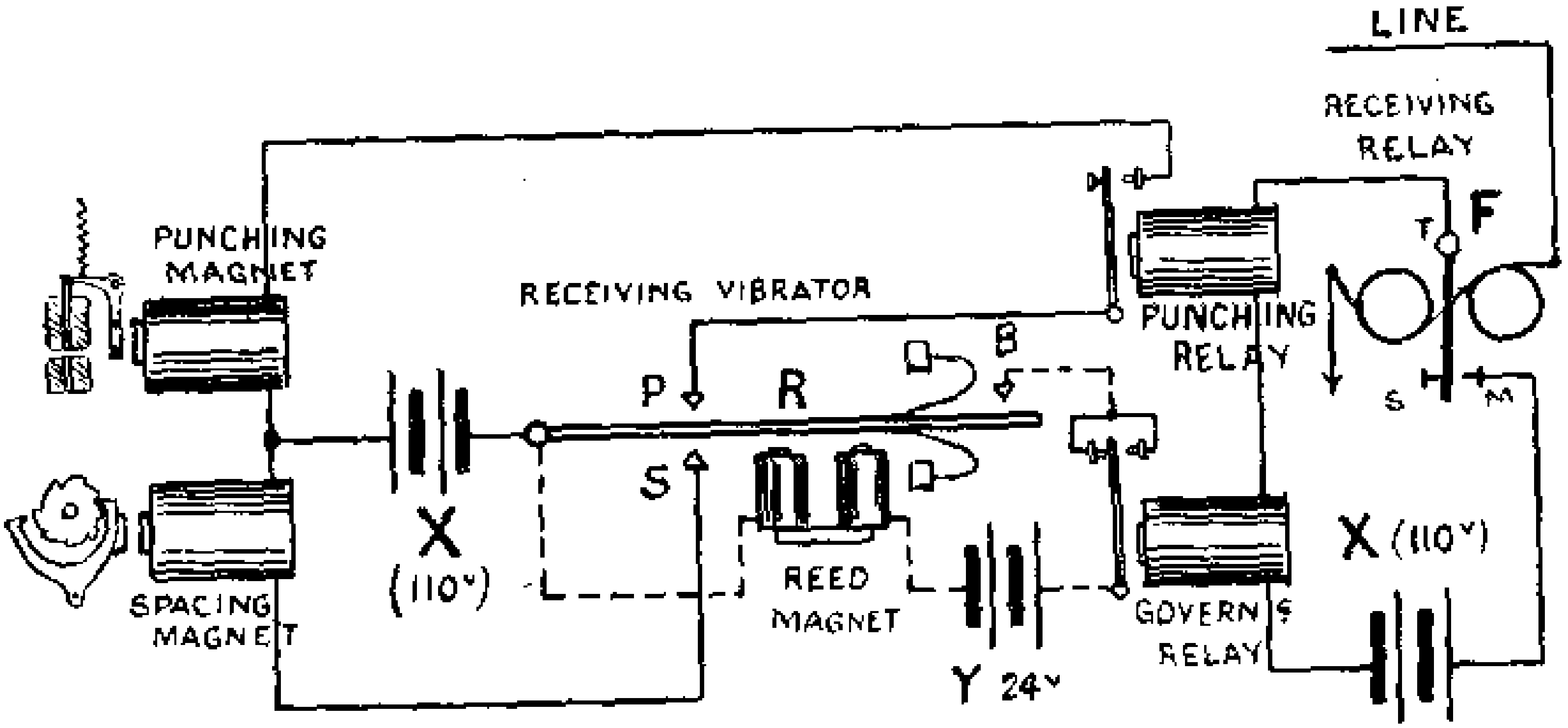


Fig. 138.—Diagram of receiving circuit.

armature will remain at rest, and the punching magnet circuit will be incomplete when the reed makes contact on that side. Hence the slip will be left plain. The spacing magnet, however, will be actuated as usual, and the plain slip will be drawn forward. The result is that the recorder slip is perforated in precisely the same manner as that passed through the transmitter at the sending end.

The reed is kept in vibration by the battery Y, and the circuit of the latter includes the contact B on the reed itself, and the contacts of the governing relay. Imagine the sending transmitter to be running without slip, or that slip punched with a long succession of Y R, Y R is being passed through it, so that simple reversals are being sent out. The receiving relay tongue will follow these exactly, but the receiving reed must vibrate at *twice* this rate. This perhaps is better seen if we imagine that a string of "letter" blanks is being received. These form a continuous marking current, but taking each unit or perforation of the tape it will be seen that, for each unit, the receiving reed must make a marking and a spacing contact. This is illustrated in Fig. 139. The upper row represents a piece of slip punched with the letters Y, R, "letter" blank and "stop" (page) signal. The middle row indicates the movements of the transmitter contact lever, the full black portions above the line being the marking, and the shaded portions below the line the spacing

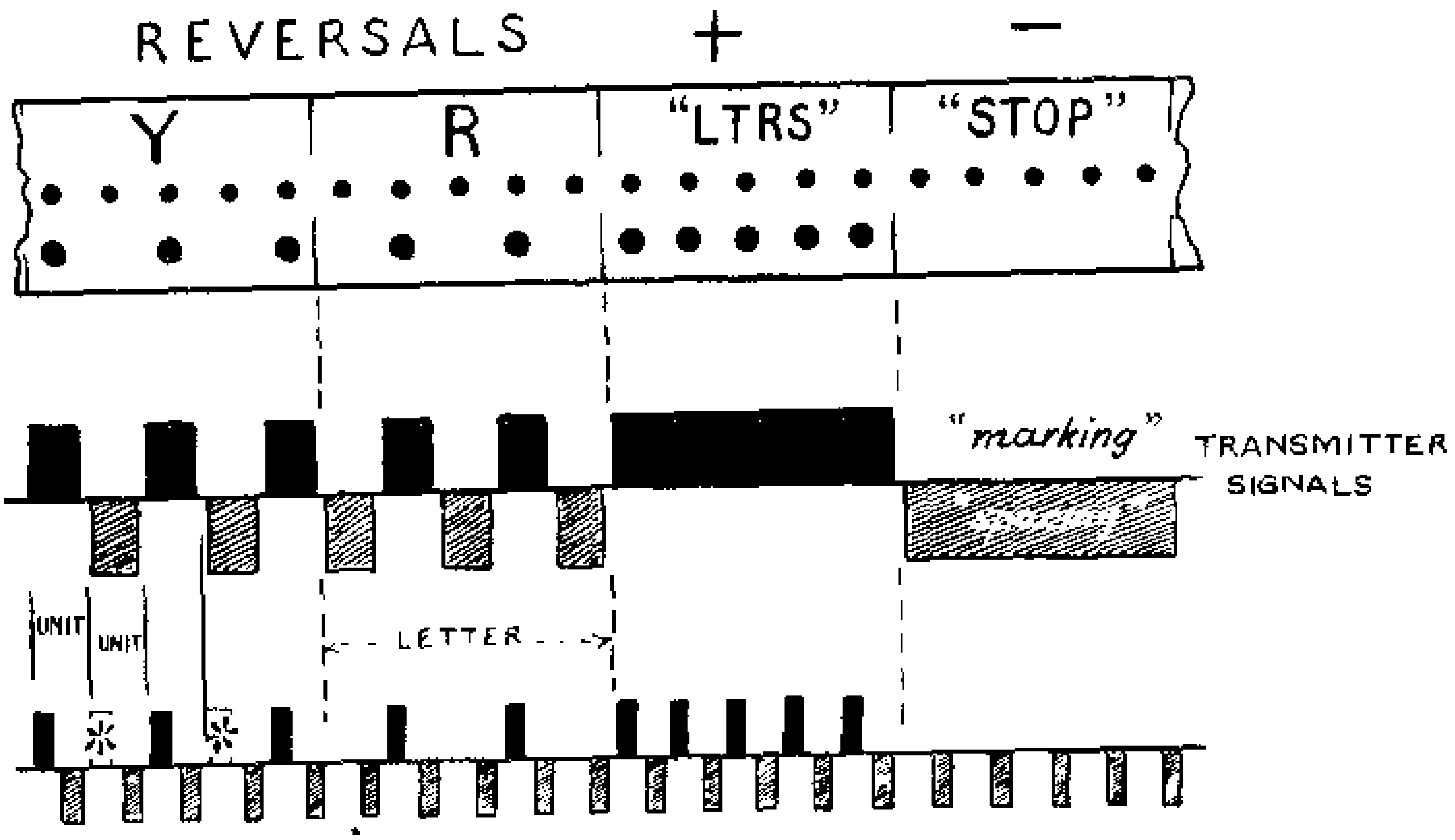


Fig. 139.

impulses. The lowest row represents the *effective* movements or contacts of the receiving reed: the black indicating the movement of the punching, and the shaded portions the movement of the spacing magnets respectively.

Thus with the first unit of current sent out (marking) the reed has to make a punching contact and a spacing one. The next unit is spacing, hence the punching circuit is incomplete, so that this impulse of the reed is ineffective, or its result suppressed as indicated by the asterisk, and so on. When the signal "letters" is received, the punching relay is permanently energised, and the punch is actuated with every contact of the reed on that side. With the "stop" signal, all the punching contacts of the reed are ineffective. This signal is utilised to break a contact on the recorder, and thus disconnect the spacing magnet circuit, and stop the feeding forward of the unpunched slip. On recommencing, several "space" signals are invariably punched, and these serve to re-start the recorder. A press button is also provided by which the punching magnet may be actuated by the receiving operator after a stoppage, and thus start the recorder again.

Governing.—The receiving reed is driven by its battery Y, whose circuit also includes the contacts of the governing relay. The armature of the latter moves every time the current is reversed. It is easily seen that if the movement of this armature (when it occurs) does not coincide with the movement of the reed, the time of duration of the contact with B will be shortened, and the pull of the reed magnet will be reduced. Under these conditions the buffer-springs tend to imprison the reed or to slow down its movements. This is the function of the governing relay, to cause the vibrations of the reed to take place in perfect accord with the movements of the receiving relay tongue.

Printer.—The upper portion of this is simply an ordinary typewriter, the depression of whose keys causes the required letters to strike the paper. Beneath the typewriter proper is the apparatus for automatically actuating the keys, when the received slip is passed through it. Figs. 140 and 141 give a front and back view of the instrument, and Figs. 142 and 143 illustrate the mechanism. The instrument shown is a hand-driven one, but a motor is now employed for driving.

Considering Fig. 142, X is one of the typewriter keys (as seen

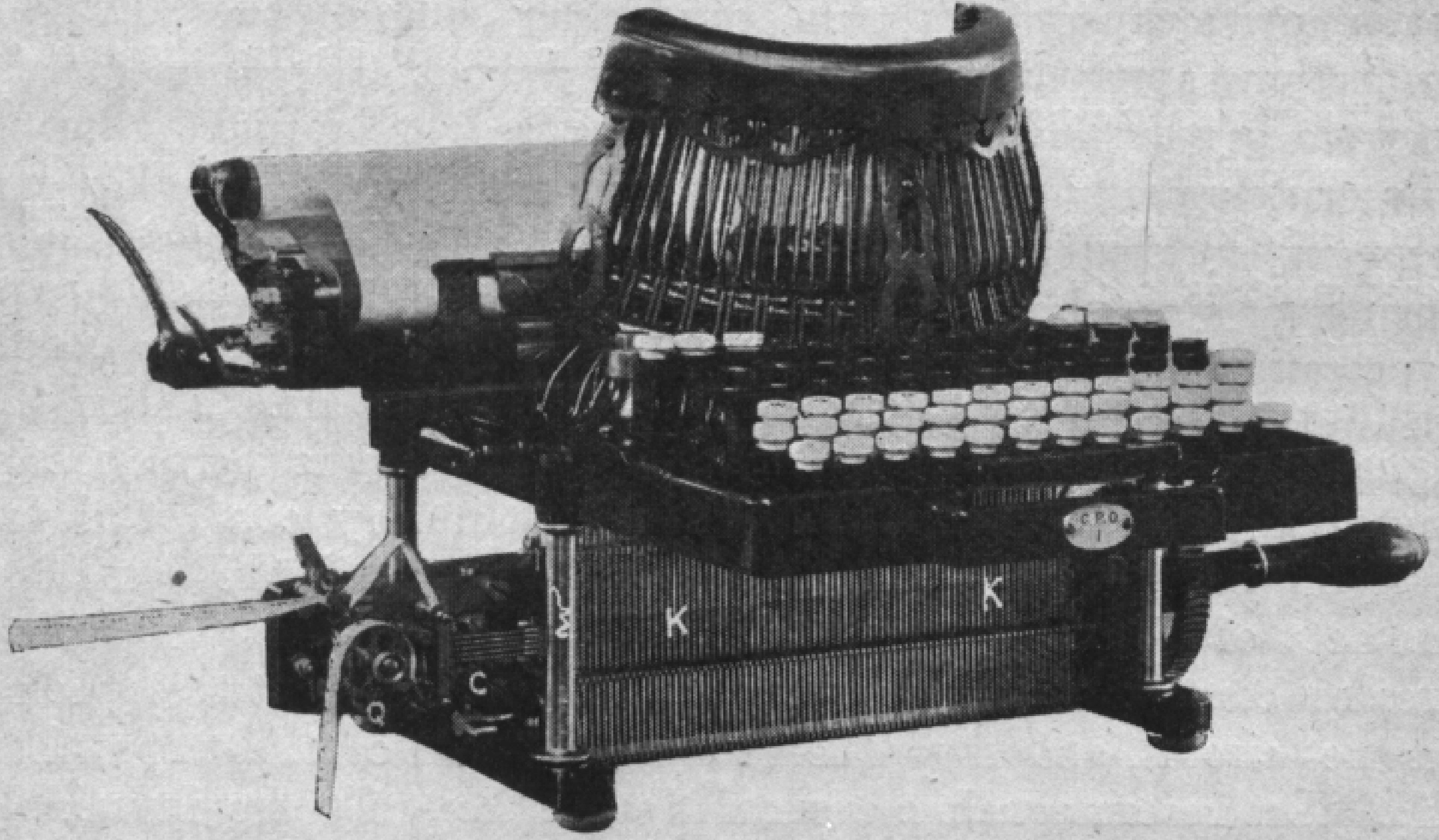


Fig. 140.—Murray printer: front.

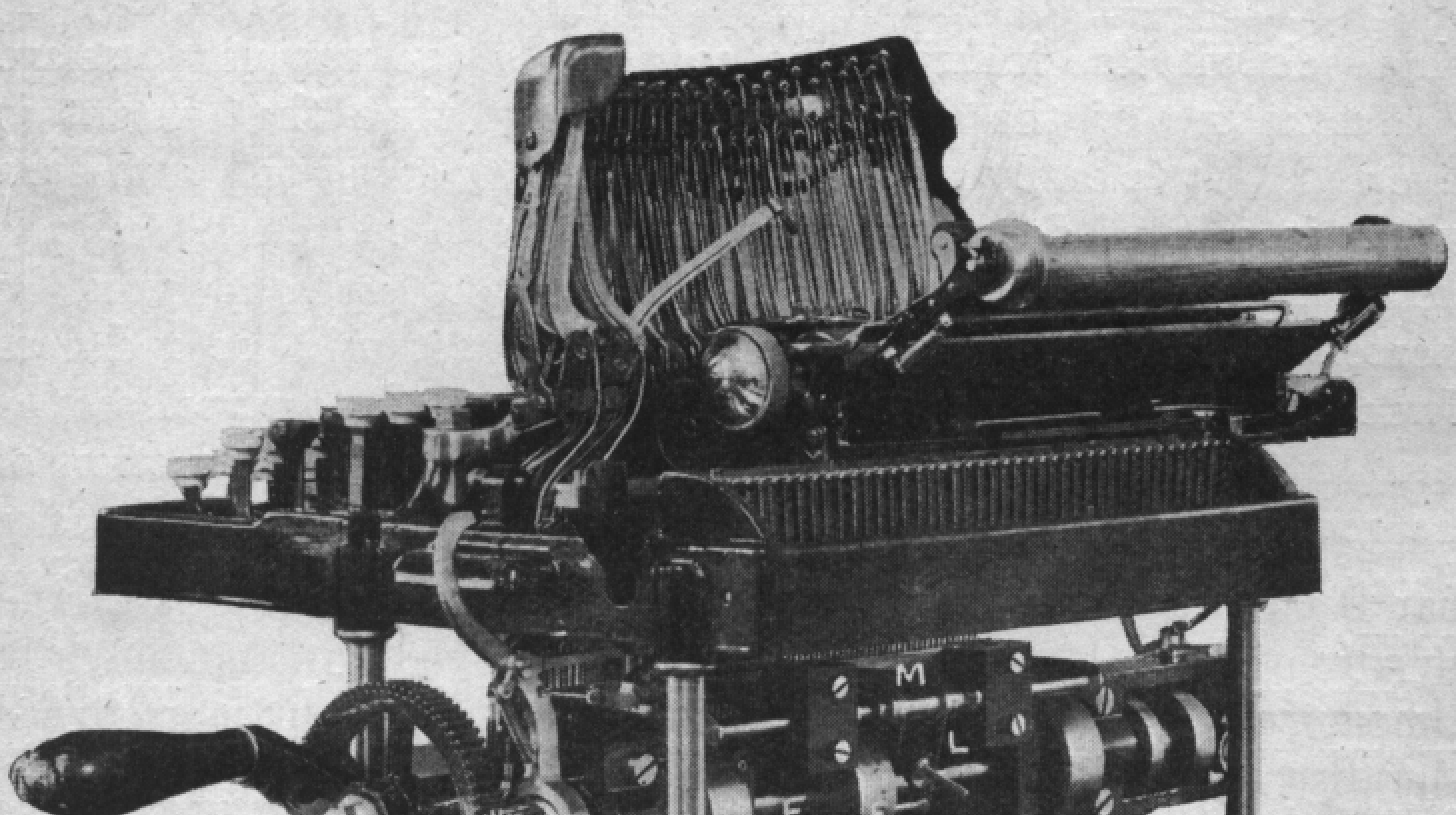


Fig. 141.—Murray printer: back.

from the side), the depression of which actuates the required letter by means of Z. On the under side of the key is a projection, Y, from which is pivoted a hook, H. Immediately in front of this hook is a strip, K, pivoted at A, and by means of a crutch at its upper end embracing the hook. The latter is kept in the crutch of K by a spiral spring, whilst a stronger spring, S, keeps K butting against the bar B. Every key of the typewriter is similarily furnished with a hook, H, and a strip, K. Behind the series of strips is the universal bar B, and six other bars or "combs" C. The latter, under certain conditions, will allow the strip K to move backwards if, at the same time, the bar B be drawn backwards also. The striking-bar J is carried by three arms M on the axle N, and is moved up and down by the shorter arm L. The latter travels in an eccentric groove in the disc E which is mounted on the shaft F.

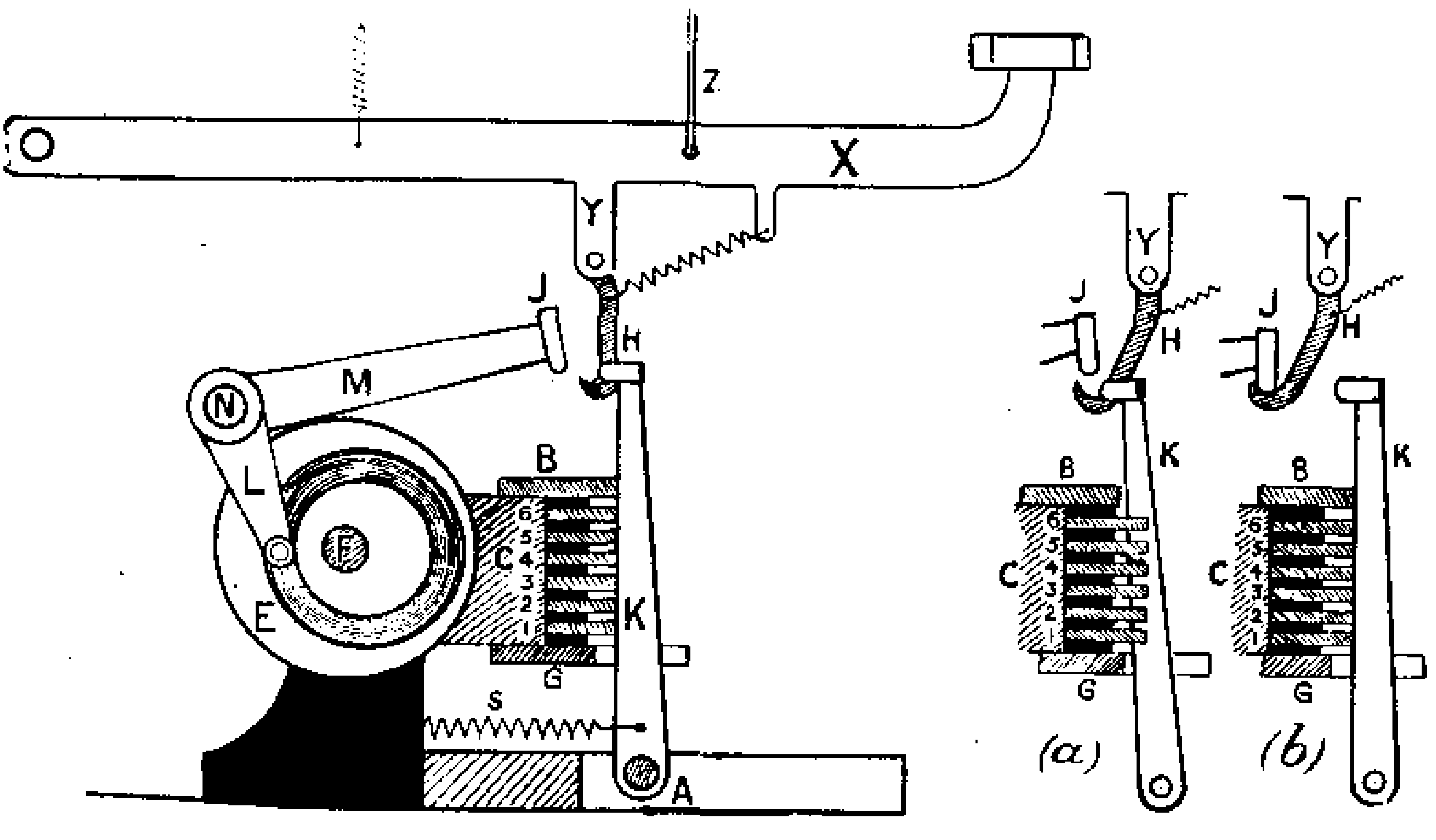


Fig. 142.—Printer: details.

When the six combs C are so arranged as to allow the strip K to move backwards, the universal bar is withdrawn and this movement of K takes place. In its movement it pushes H towards J as shown at (*a*) in Fig. 142. The striking bar descends and engages with the hook. The bar B then resumes its old position, restoring K and leaving the hook H engaged with J, as at (*b*) in the same figure. J then descends and pulls down the key. Having done this, J rises and the hook is drawn back into the crutched end of K by its spiral spring.

We now come to Fig. 143. Five of the strips K are shown with the projections Y from five keys, as seen from the front. The bar B and six combs C are seen running right and left behind the vertical strips. The five lower combs are provided with pointed ends on the left whilst the sixth is not so provided. For the present we shall consider only the five pointed combs, one of which is shown in the lower part of the figure (on a much smaller scale). From the latter it will be seen that the front edge, which is presented towards the strip K, is full of notches or is irregularly toothed. Now if all the combs were notched regularly and alike, so that a continuous vertical notch or slot existed behind each of the strips K, then on the withdrawal of the universal bar all the strips would move backwards and all the keys of the typewriter would be actuated. The notching, however, is irregular and each comb is notched differently to the others, so that with all the combs in their normal position (as in Fig. 143) there is not a single continuous slot. The withdrawal

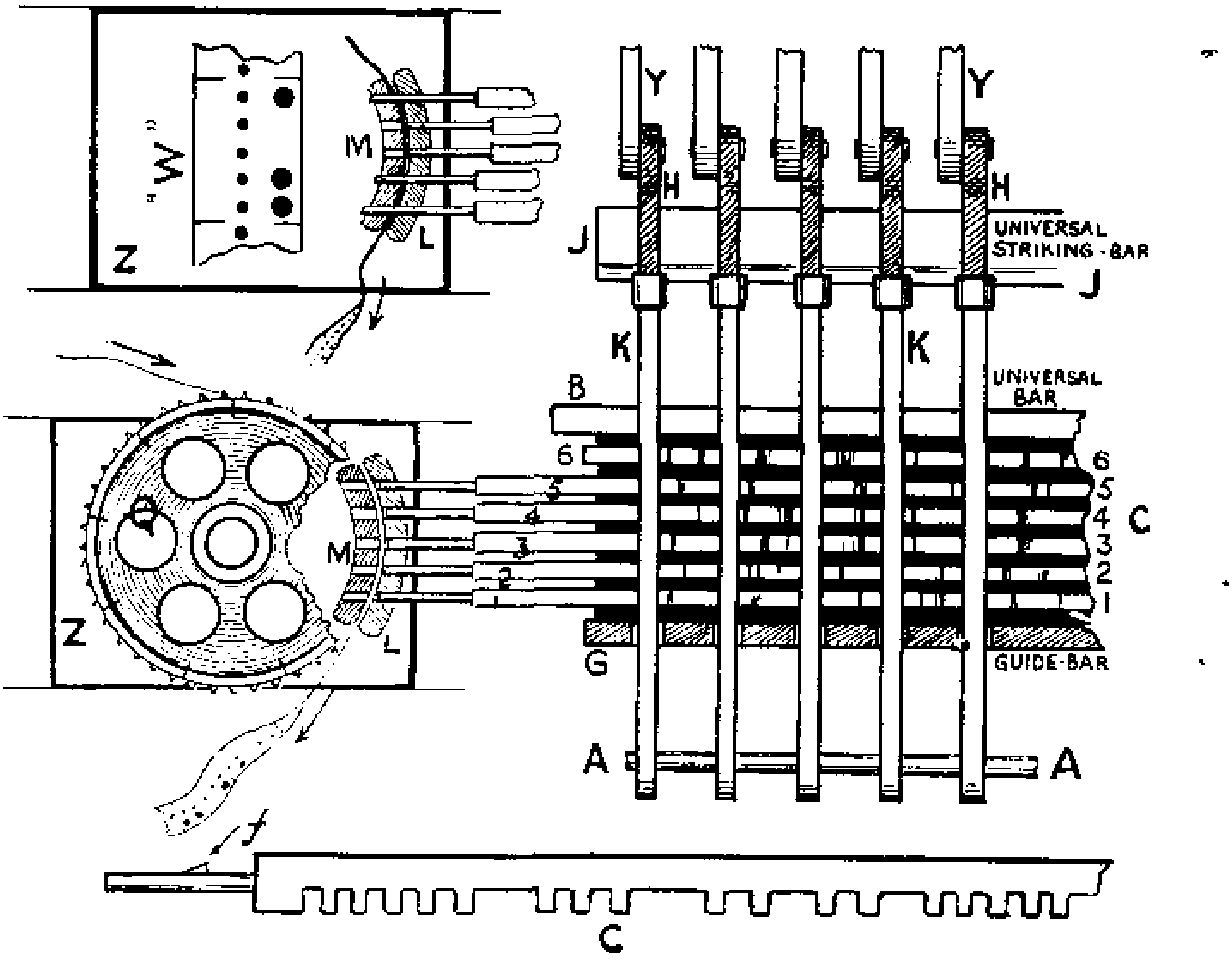


Fig. 143.—Printer : details.

of the bar B under these conditions would have no effect, all the strips remaining unmoved.

But each comb is capable of sliding to the right by about $\frac{1}{16}$ inch, and the effect of such movement is to cause a continuous slot to be formed behind one of the strips. Imagine combs 1, 2, 3, and 4 to have a notch in each, exactly opposite, so that the notch is continuous across the four, but that No. 5 is unnotched in this region. Obviously the latter prevents the movement of its corresponding strip. If, however, the movement to the right of the fifth comb brings a notch in line with that in the others, the slot will be continuous, and on the withdrawal of B the strip will enter the slot and the corresponding key will be pulled down. This movement of the combs is brought about by the perforated slip. Each, as we have seen, is provided with a pointed end. To the left of these ends is a star-wheel, Q, round which the slip passes. Immediately opposite the combs is a guide, L, in which the pointed ends normally rest. Behind L is another guide M in exact alignment with it. The front of M is of the same radius as the star-wheel, and the faces of the two are arranged so that when the slip is brought between M and L by the movement of Q, the lower perforations are in line with the holes in the two guides whilst the central perforations engage with the projecting teeth of the star-wheel. Q and the other parts are mounted on a little carriage, Z, which is moved towards the combs and then withdrawn—both movements being effected by a cam on the shaft F (Fig. 142).

If now the carriage moves to the right—no slip being on the wheel—the pointed ends of all the combs enter the guide M, or rather the latter slides over the ends and no displacement of the combs occurs. But suppose slip to be inserted punched with the letter "W." As the carriage moves to the right the first, second, and fifth combs enter M, as the slip is perforated in the line of these guide-holes. As the slip is continuous in the region of the third and fourth combs these cannot pass through to M, but are pushed over to the right, as shown in the upper left-hand corner of Fig. 143. This arranges a continuous slot behind the strip K of the required letter, and on the withdrawal of the universal bar the strip falls and the letter is printed. The carriage moves back to its normal position and in its journey restores the combs to their old position by means of the little projection *f* on the pointed end (Fig. 143).

In every revolution of the shaft F we have the following:—The carriage Z moves to *the right, setting* the combs and opening a slot for the required letter; B is withdrawn, K moves backward, *carrying* H; the striking bar engages with H; B restores the strip K; J pulls down the key and then releases the hook H; the carriage returns, re-sets combs in alignment, and moves slip forward.

Letters and Figures.—The 5-unit alphabet, as we have noticed, gives us 29 *signs* or combinations. But these are practically exhausted in representing the alphabet alone. The *same signs* are, therefore, used for figures, &c., also, by prefixing a "letter" or a "figure" signal. This is the office *of the sixth* comb, of which we have not yet treated. This is notched in such a way as to permit of the *making of the* combinations we have just considered. That is, wherever a slot is made continuous *across the* five combs for a particular letter, the sixth comb is also notched, so that its co-operation is not required. *If, however,* the signal "figures" is punched, one of the strips K moves backward as usual. The strip does *not actuate a key*, but pushes the sixth comb slightly to the right by a wedging action. This has the effect of *barring all the* previous possible slots, and opening up a fresh set in the region of the figure keys. Any *combination on the* slip will now cause figures, &c., instead of letters, to be printed. When the signal "letters" is punched, another strip is actuated which pushes the sixth comb back to the left, thus barring the figure *series and re*-opening the letter series.

In other words, the *notching on* the five combs is such that a certain combination—say "W"—causes *two* continuous slots *to appear in* the five combs, one behind the strip which actuates the letter "W," and the other behind the strip *actuating the* figure "2." With the sixth comb in the "letters" position, however, a notch occurs in it *in line with the letter* "W," and an unnotched portion in line with "2." Hence the letter is actuated. *With the sixth* comb in the "figures" position the notched and unnotched portions are reversed, and the figure is *printed*.

The function of the "space" signal is simply *to actuate* the spacing key of the printer, and is unaffected by the position of the sixth comb. The "*line*" *signal* actuates special mechanism in the printer by which the printing is temporarily stopped and

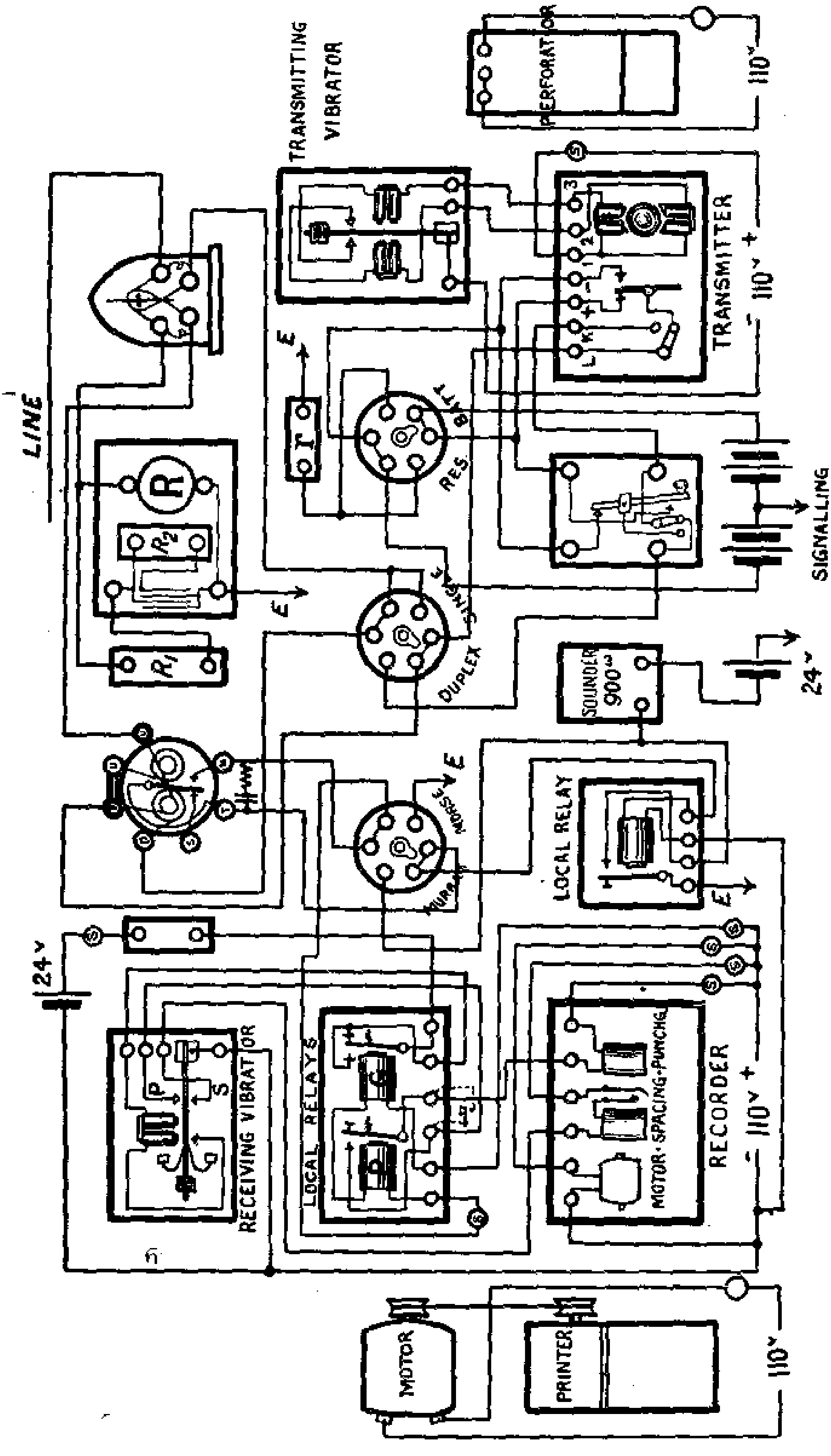


Fig. 144.—Diagram of Murray system.

the typewriter carriage run back so as to start a fresh line. This done, the printing re-commences.

Duplexing.—We have hitherto considered working one way only—*i.e.*, with the sending apparatus at one station and the receiving at the other. The system, as will readily be seen, is not adapted for alternate sending and receiving; if, therefore, one wire only is in use, duplex working is essential. This is accomplished on the differential plan, the transmitter sending to the split of a differentially-wound relay. The diagram of connections is given in Fig. 144. A Morse key and sounder are added to the equipment for speaking and balancing purposes, a switch bringing either the Murray or the Morse into use at will. In the former position a third local relay is in series with the punching and governing relays, and this actuates the sounder. The Murray signals are, therefore, constantly heard on the latter. When the switch is turned to Morse, the sounder only is worked by the line relay tongue.

CHAPTER X.

TEST AND BATTERY BOXES.

When an office has but a single wire, and, consequently, but one instrument, the line is naturally brought direct to the latter. To disconnect or earth such a line the necessary arrangements must be made at the instrument itself. As soon, however, as the wires number more than two or three, it is obvious that such rough-and-ready means become impracticable, and a test board is introduced to which all the wires are brought, and from which the leads proceed to the respective instruments. All testing operations can then be performed at this board, and it forms a natural and easy means of distinguishing between instrument faults—or those in the office itself, for which the latter is responsible—and line or other faults outside the office and over which the station has no immediate control.

Similarly with the batteries. With one or two circuits the necessary cells are brought as near as possible to the instruments. At offices beyond this stage a separate room is demanded, which arrangement has the further advantage of rendering easier the operations of renewing, recharging, and maintenance generally. Hence the battery wires are conveniently brought to a battery box or board, where one set may easily be substituted for another, power increased, &c.

Screw-terminal Type of Board.—The oldest form of test and battery box alike is the screw-terminal pattern, illustrated in Fig. 145, and is the standard for stations having a comparatively small number of circuits. On a board of mahogany or teak is fitted a number of terminals, each of which is provided with a long shank which passes through the board, and has the connecting wire permanently soldered to it. For each line on which an instrument is placed four terminals are needed, but by combining those for two lines in one vertical row, seven terminals serve. The lines are brought to the uppermost and lowest terminals of such sets of seven, the middle one, which is blackened, serving as a common "earth," and the remaining two pairs are connected to the respective instruments. This is shown in the panel marked "lines."

If the office in question be intermediate on any circuit, one pair of instrument terminals will be thrown out of use, and those of the other pair connected to the two lines as in the first position. Where an office is on the direct route of a main line, the main line wires are generally led in for convenience of testing and localising faults. As these simply pass in and out, the office not being in circuit on them, two terminals will, of course, suffice for each.

The batteries are naturally arranged, with their instrument terminals, in sets of four, forming the corners of a square. The upper pair consists of the positive and negative leads, and the lower the instrument leads.

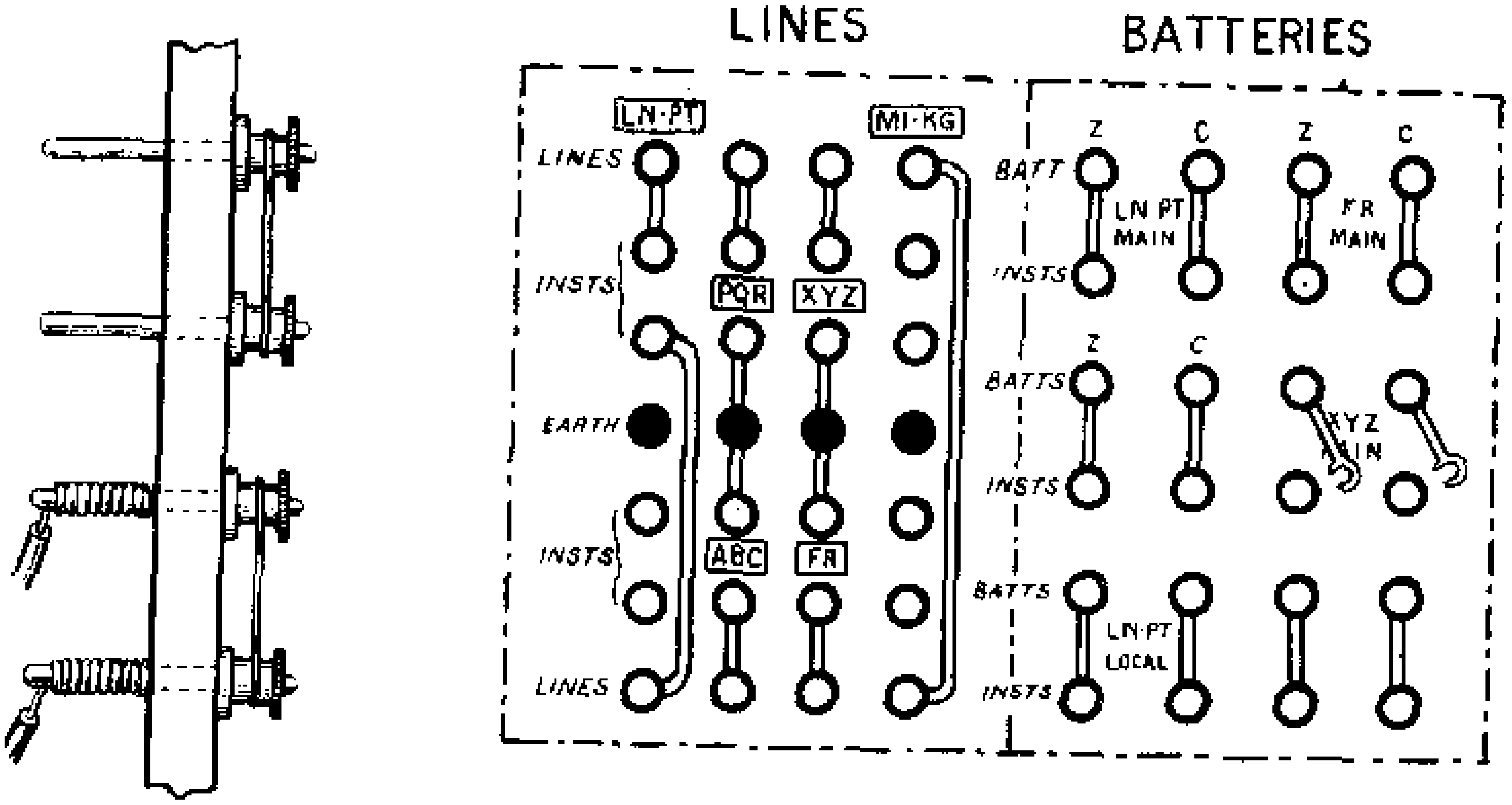


Fig. 145.—Test-box: screw-terminal pattern.

Test-hole and U-link Board.—In another form of test and battery box "test-holes" and "U-links" are substituted for the terminals and their connecting wires or straps, and an ebonite plate for the wooden board, as in Fig. 146. A series of holes is drilled in the plate, and these are fitted with tubular linings of brass, to which the permanent connection is soldered. At the front of the box connection between two holes is made by the insertion of a U-shaped link, the limbs of which fit the test-holes pretty fairly, and which are split at the ends so as to undergo slight compression when inserted, and thus secure good contact.

Boards of this type are very compact, and give a much larger capacity for the same area. The four test-holes for lines (line, earth, and two instrument terminations) are arranged diamond fashion, with the long diameter horizontal. Two diamonds are placed close together so that the inner test-holes form a common earth, as shown in the figure. To reverse a set from "up" to "down" station it is simply necessary to reverse the inclination of the links. The battery test-holes are similarly arranged to form a diamond, but the longest diameter is vertical. Each set of four is separate. The battery can be reversed, as before, by reversing the inclination of the links. To make connections between other than neighbouring test-holes a pair of pegs, connected by a single conductor flexible cord, is used. In cases where the "earth" is obtained at the instrument tables, one instrument lead only is necessary, and the two test-holes are then placed in a vertical line.

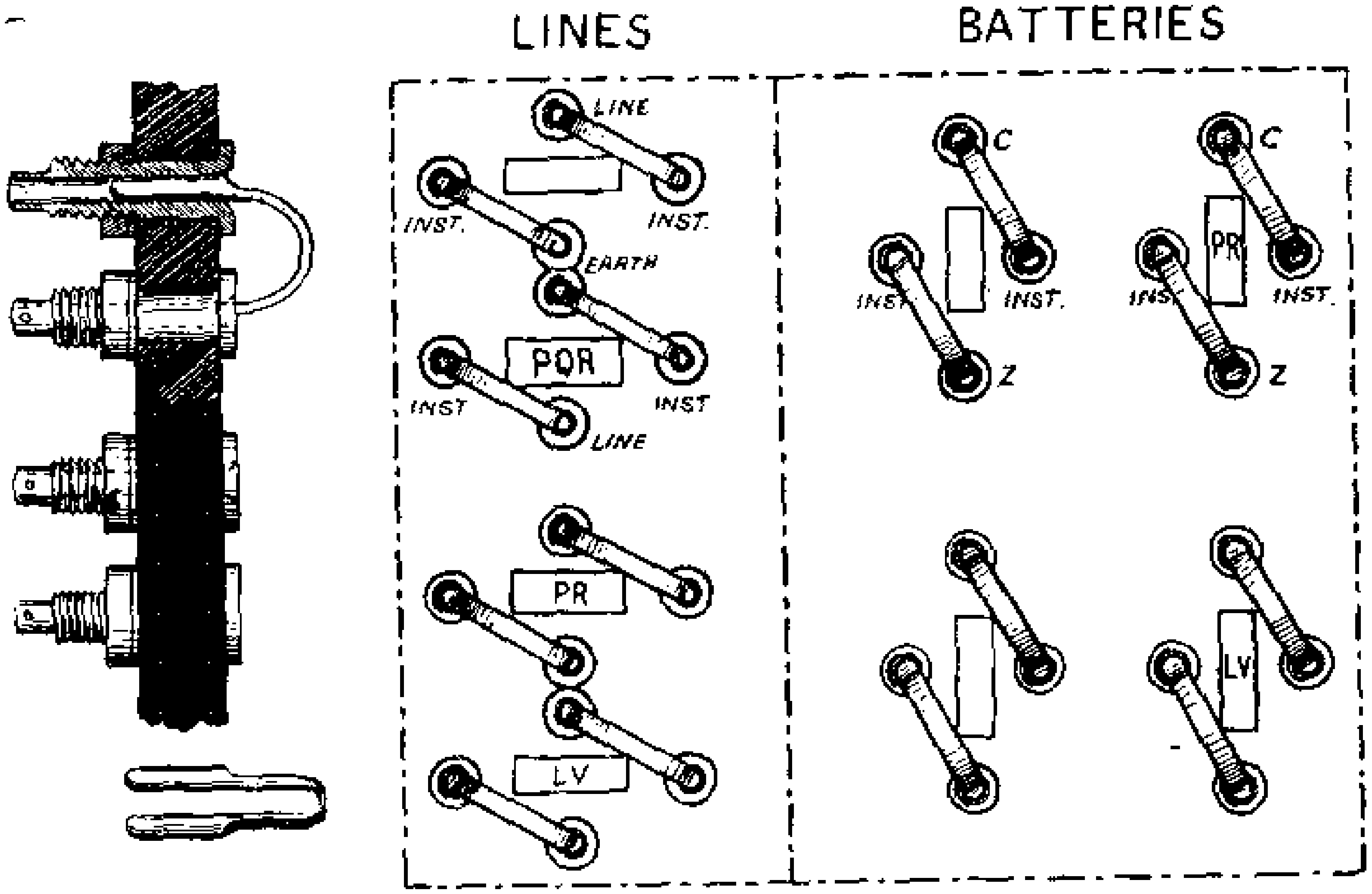


Fig. 146.—Test-box; test-hole and U-link pattern.

Test-box Detectors.—For the simpler testing operations a test-box "detector" is added to the equipment of the line and battery box. Fig. 147 illustrates a much used form. A wooden case has a galvanometer coil mounted in its upper part, whilst below is a circular switch and three terminals. Small brass pegs are used to connect any of the four quadrants X, Z, G, and C together or to the outer ring which is to earth.

In many cases it is now the practice to use an ordinary differential galvanometer with the test-box. This is mounted on a brass turntable bracket which allows the instrument to be turned at any convenient angle. A test-hole switch for making the various connections completes the equipment.

Switch-spring Test-board.—Up to the present we have considered combined test and battery boxes, using primary batteries only. Where secondaries are in use, however, the two are separate, the battery box then being replaced by the instrument room distributing cabinet and the table cases. The line box in such offices is of the switch-spring form shown in Fig. 148. The terminals of the oldest and the test-holes of the more recent forms are replaced by "switch-springs" of the telephone switchboard type.

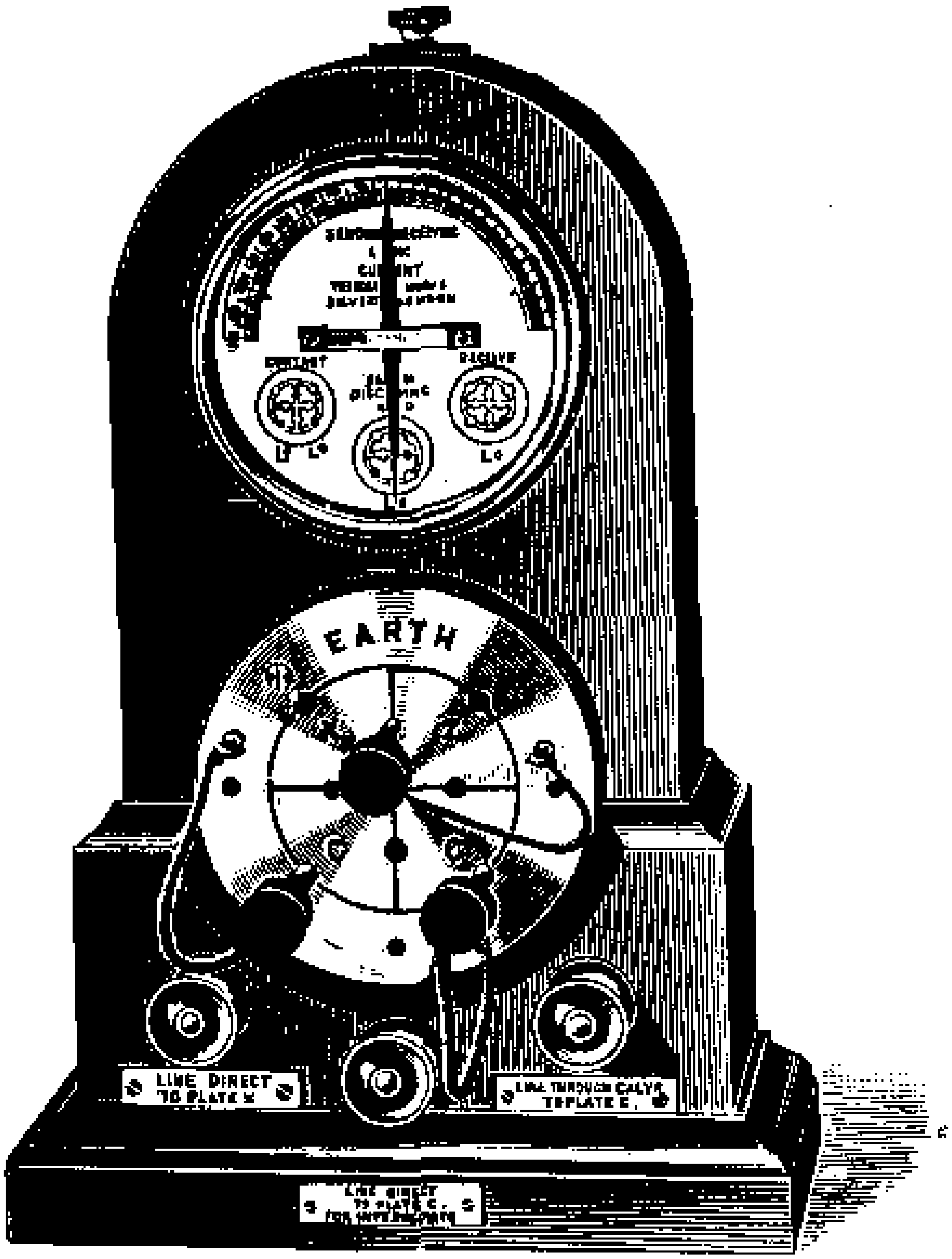

CURRENT
RECEIVE
EARTH
LINE DIRECT TO PLATE X
LINE THROUGH GALVS TO PLATE E
LINE DIRECT TO PLATE C

Fig. 147.—Test-box detector.

The switch-springs are of the five-point variety—*i.e.*, consisting of five parts to which connection can be made, two short inner springs, a long and a short outer spring, and the socket. The latter is not used. The two inner springs normally make contact with the upper and lower springs respectively. For the purpose of the test-board, the two outer springs are connected together by their back ends or "tags," and connected to the line. A second switch-spring, beneath the first, has its outer

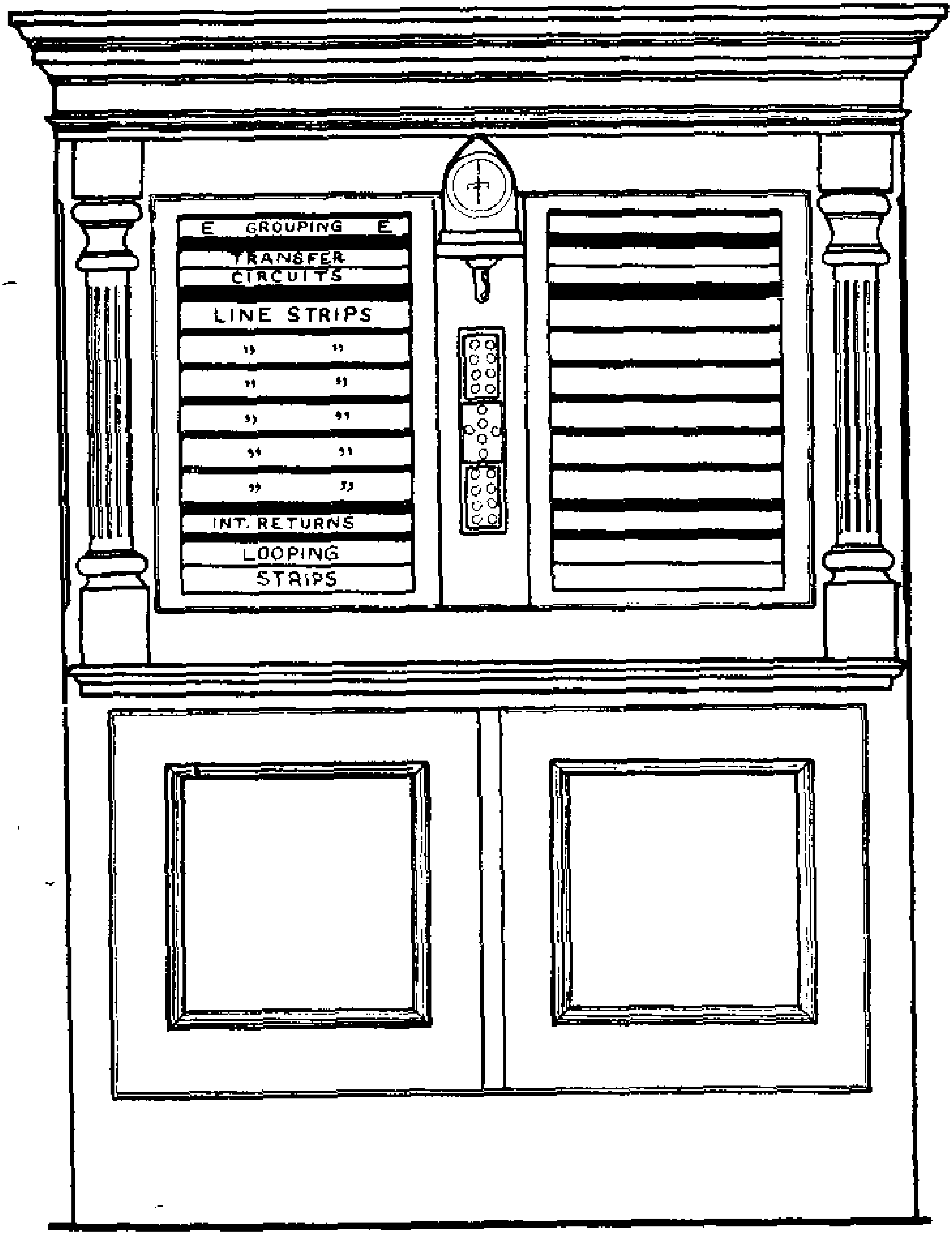


Fig. 148.—Test-board: switch-spring type.

springs similarly connected to one side of the instrument. The two inner springs of the first are then connected together, and joined to the inner springs of the second. By this means the line is normally through to the instrument without any external (front) connections whatever. When it is necessary to get at the line, say for testing, and to disconnect the instrument from it, a simple peg with a solid brass shank is inserted into the line switch-spring. The long springs are forced open by the insertion of the peg and quit their contact with the inner springs, and make a new connection with the peg. As the metallic portion of the latter is a single piece, the line is brought by both springs into contact with the peg, and disconnected from the instrument. This peg is one of a pair connected together by a single conductor flexible cord. If it be desired, the instrument itself may be similarly got at, and the line disconnected from it by inserting a peg in the instrument switch-spring.

The general practice now is to earth the instruments at the tables themselves in the case of terminal offices. Thus two switch-springs suffice for each circuit. In the case of intermediates, of course, four are required.

These test-boards are made up of one, two, or any number of panels. The line switch-springs are mounted in a double row of twenty on a strip, 2 inches wide. There are thus forty on a strip, giving accommodation for twenty lines (terminal stations). Six of these strips are mounted on each panel, the capacity being, therefore, 120 lines. Below this series of six strips is a narrower one with a single row of twenty switch-springs. These are intended for instrument return leads. Below this strip are fitted, where necessary, two other narrow strips, each with one row of twenty springs. These are the "looping strips," and are for use where the wires are looped for the morning test. Two lines which have to be thus looped are brought to the upper and lower springs of a single switch-spring, whilst the inner ones then go to the respective "line" switch-springs of the two circuits. The insertion of a peg, with its solid metal shank, into the "morning test" hole then cuts off communication with the inner springs, and the two lines are then automatically "looped."

If the test-board consists of a single panel, the space above the six line strips is occupied by a test-box detector (a plain galvanometer coil), and a circular seven-hole tablet. If the test-board has two panels, as shown in Fig. 148, the detector is replaced by a differential galvanometer, mounted on its bracket, fixed at the upper part of the division which separates the two panels. Beneath the galvanometer is placed an oblong tablet of

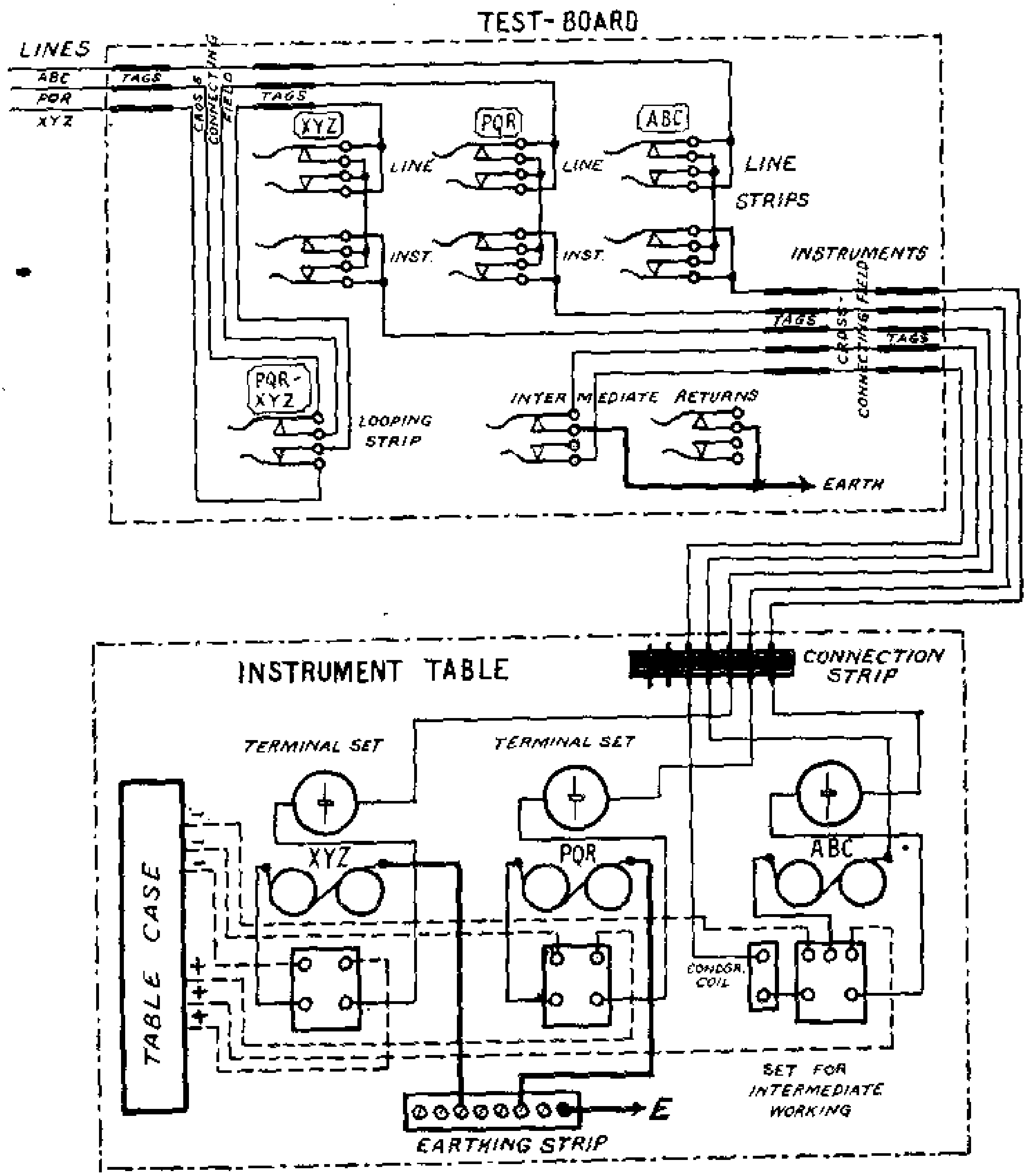


Fig. 149.

twenty-two test-holes, or, rather, a central one of six, and one above, and one below this of eight test-holes each. The galvanometer, and its testing battery, &c., are brought to the central one, whilst the others are utilised for the tangent galvanometer terminals, Wheatstone bridge, speaking sets, &c. If of more than two panels, each division is fitted with galvanometer and switch. The space in each panel above the line strips is then occupied by three other strips, each having a single row of twenty switch-springs. The uppermost has its springs connected together in groups, one of these groups being to earth. These are required, if it be necessary to earth or to "bunch" several wires simultaneously. The other two rows are for "transfer circuits"—*i.e.*, communication between one panel and another.

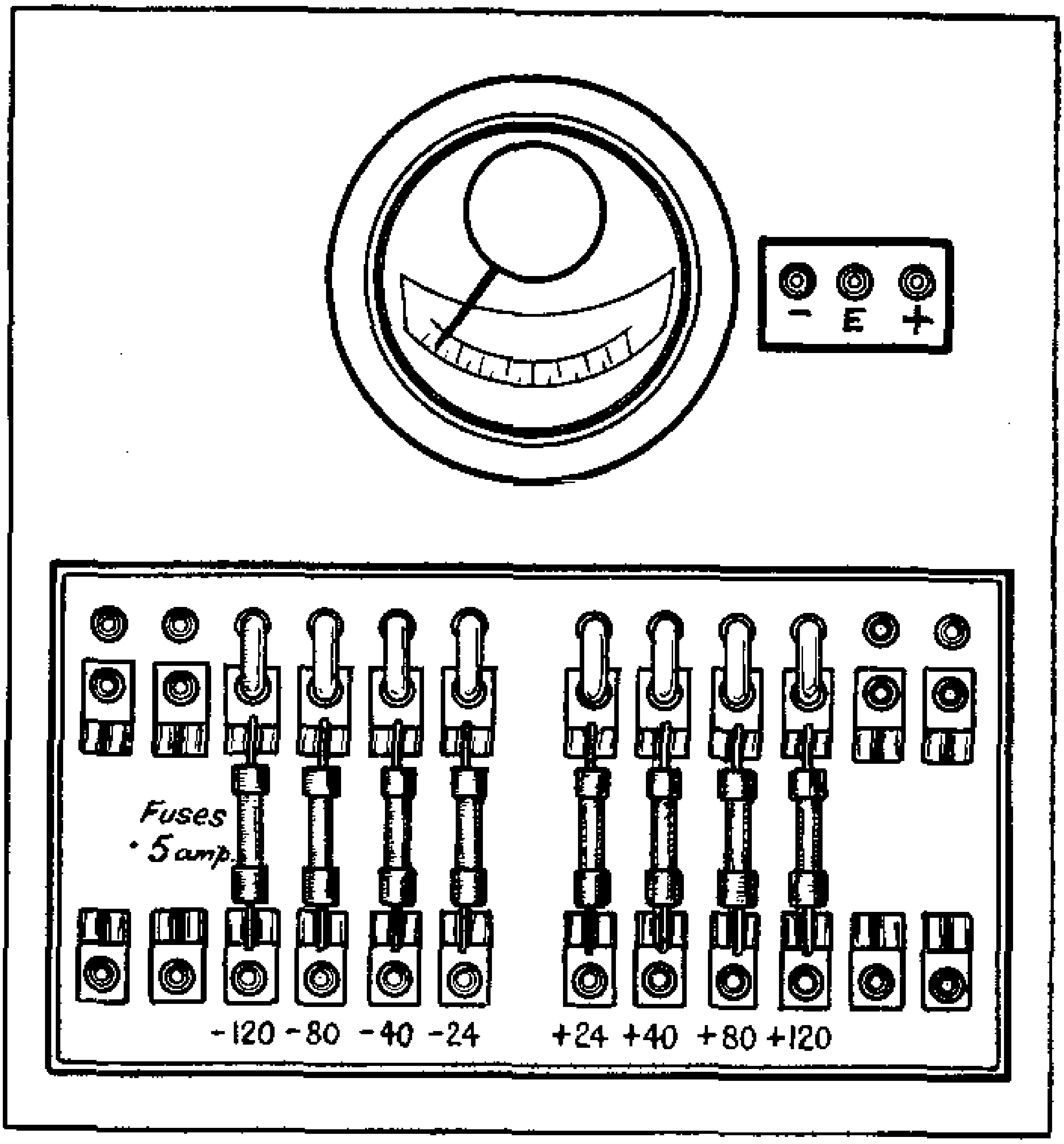


Fig. 150.

Fig. 149 illustrates the wiring of the test-board, and its connection with an instrument table. The line A B C is brought to the line strips, thence to the table. The lines P Q R and X Y Z are brought to the looping strip, and thence to the line strip for morning test purposes. The *two latter* are earthed at the table. The instrument A B C, however, finds *earth* by means of a second lead (from the relay) at the intermediate return strip. This arrangement is to enable the set A B C to be used as an *intermediate* station. In the terminal arrangement (as shown) the lead *from the key through the* "condenser coil" is disconnected. To make it intermediate, the *second line* is plugged into the intermediate return switch-spring. The relay is thus disconnected from earth, and joined *to the new line*, as is also the lead from the left of the key. The condenser coil is placed in this lead in order to balance up the resistance of the two lengths of line, the shortest being put on this side for that reason.

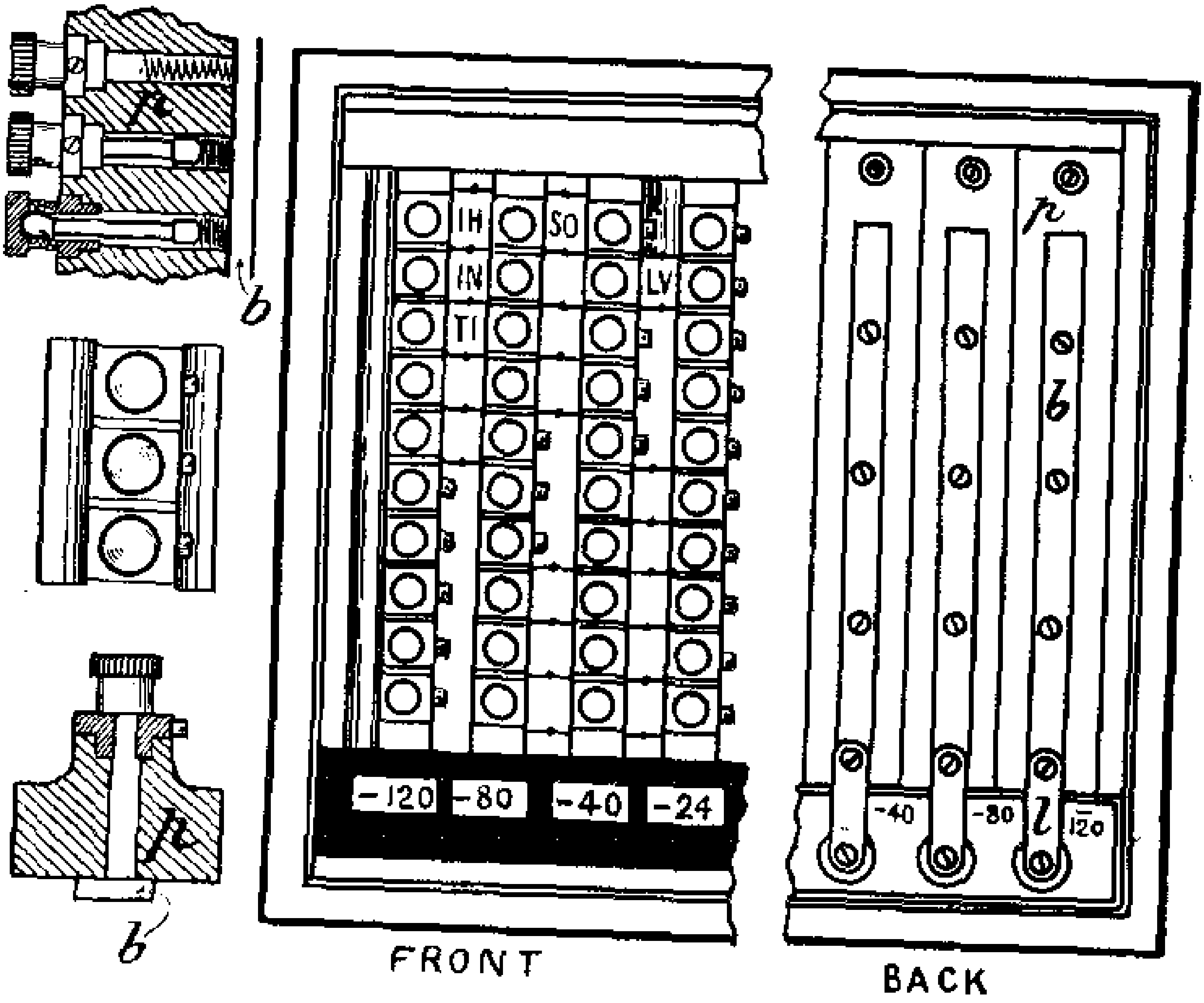


Fig. 151.

At the test-board it will be seen that there are two sets of cross-connection tags. These are to enable any *convenient* positions to be allotted to the lines on the one hand, and table positions on the other.

Instrument-room Cabinet.—This is in use where secondary batteries are installed and replaces the battery box of the primary system. Fig. 150 illustrates the essential parts minus the containing case. The leads from the secondary cells are brought to this and distributed to the table cases. On an ebonite tablet is mounted twelve combined fuse-holders and test-holes with **U**-links. In each fuse-holder a 5-ampere "fibre tube" fuse is placed. A voltmeter and a three test-hole tablet is fitted above.

Table Cases.—Every third table in the instrument room is provided with a table case ("distribution and fuse case"), and the power leads from the instrument room cabinet are carried to these. Fig. 151 gives a front and back view, and on the left a section, &c., of the fittings. Eight vertical porcelain strips *p* have at their backs eight vertical brass strips *b* to which the power leads are connected. In front, each strip *p* carries ten screw fittings which, when in position, make contact between the brass strip at the back and a screw in the side (normally covered up by the label) which is connected to the instrument. The contact is made by means of a 1-ampere glass tube fuse and a spiral spring as seen in the upper section on the left in Fig. 151.

CHAPTER XI.

CIRCUIT CONCENTRATION, &c.

Concentrator Switches.—At an office having many local circuits it rarely occurs that all the instruments are working at the same time. In practice an operator having finished on one circuit moves on to any other demanding attention. To avoid the inconvenience and loss of time in shifting about and to effect an economy in the actual number of instruments employed on a given number of lines, concentrator switches are employed. Each line is then normally through, not to a working instrument,

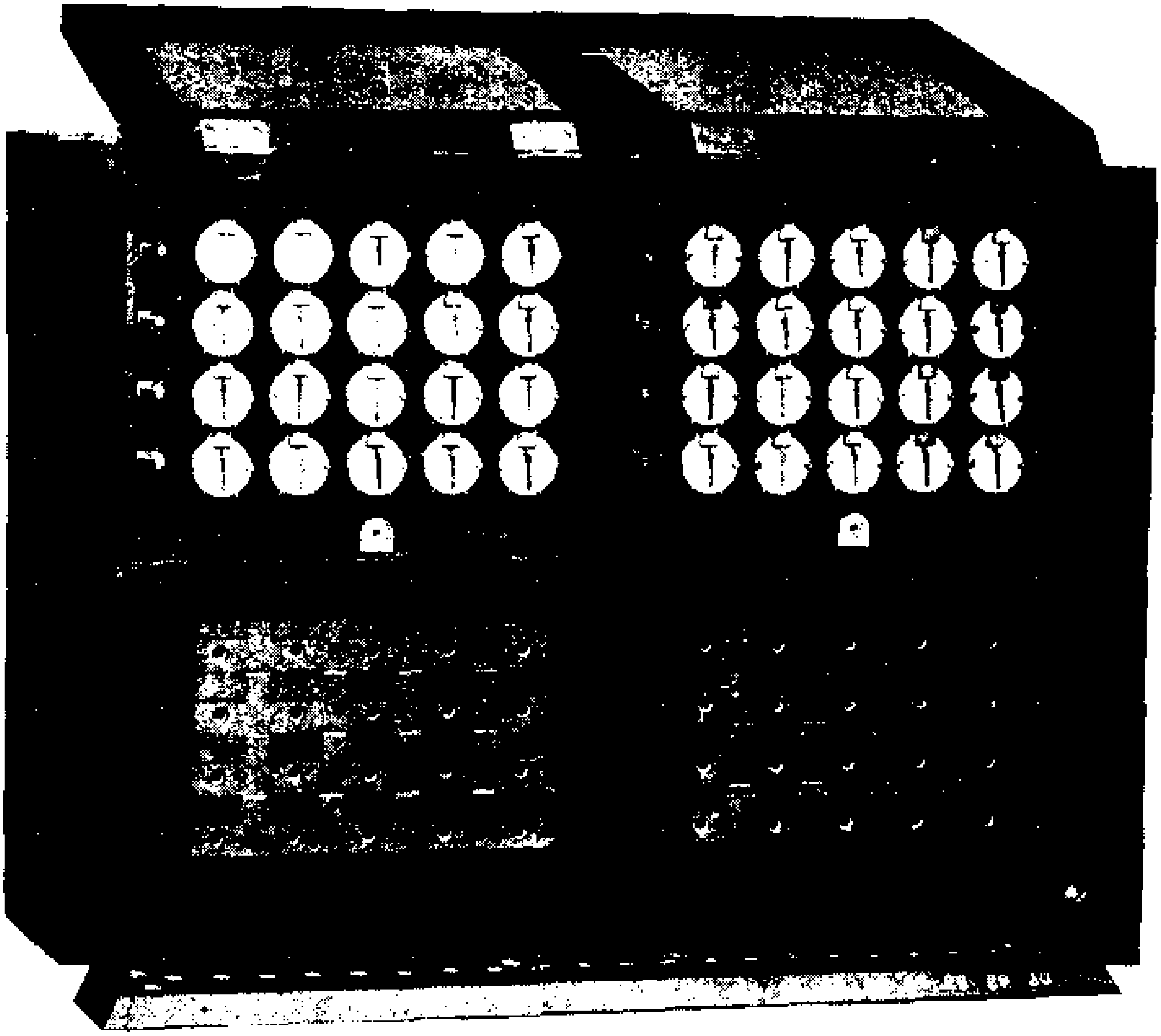


Fig. 152.—40-line concentrator switch.

but to an indicator which occupies but little space. The working sets are provided with pegs and cords, so that any one of them can be put through to any circuit by the insertion of its peg in the required switch-spring. When this circuit is clear the peg is withdrawn and inserted in another circuit demanding attention. The operator indeed is fixed and the lines are brought to him. Thus the total number of working instruments is less, and often considerably less, than the number of lines. The plan is then to keep two or three instruments continuously employed and to use more as occasion demands.

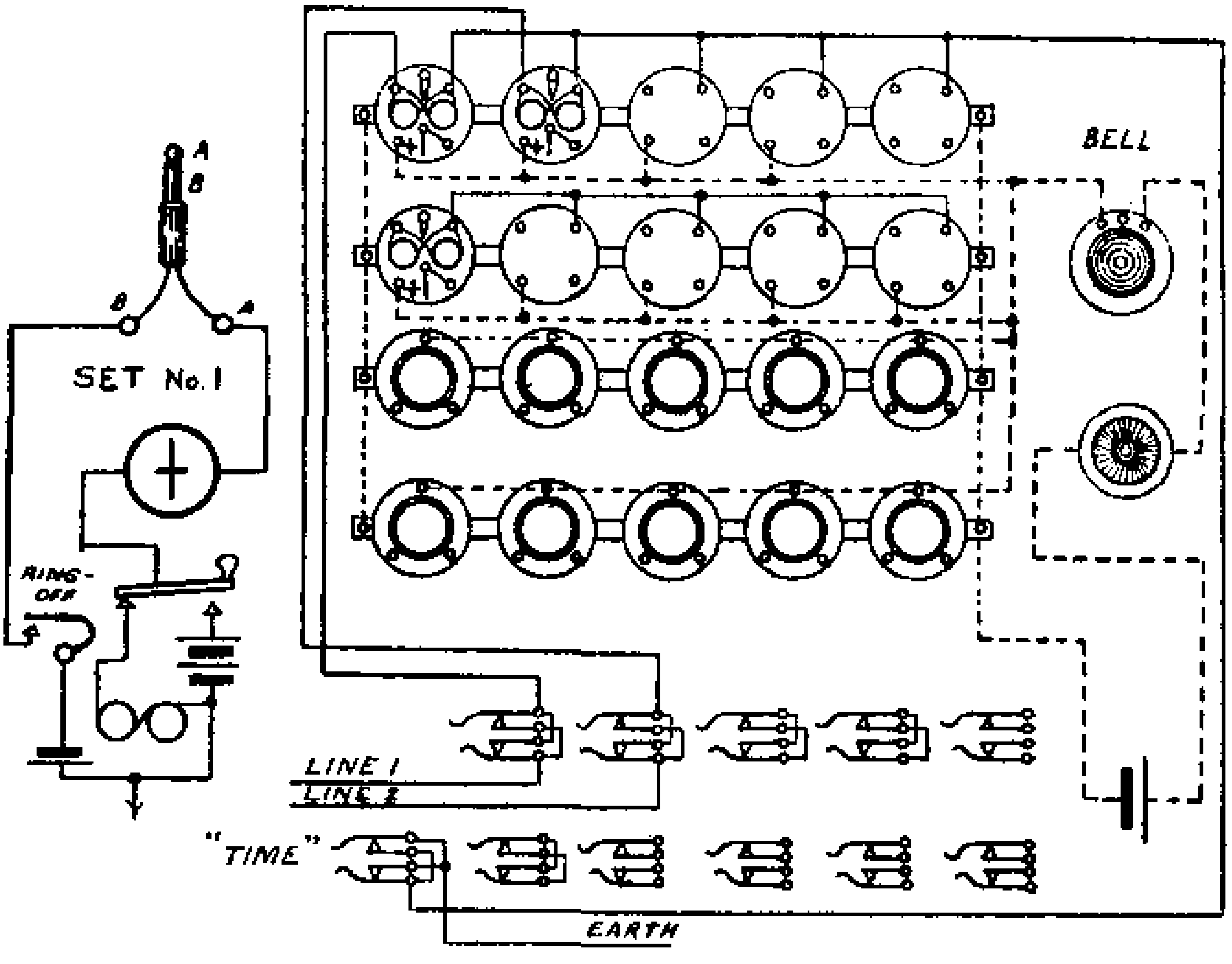


Fig. 153.—Concentrator: connections.

The present standard form of concentrator switch is illustrated in Fig. 152, each panel accommodating twenty lines. For A B C circuits the lines are terminated on small non-polarized indicators. Single-needle, double-plate sounder and ordinary sounder circuits (single or double-current) are terminated on the polarized indicator relays shown in Fig. 152. The switch springs are of the 5-point variety described in the new form of telegraph test-box. The arrangement of lines and indicators is shown in Fig. 153, which assumes that the upper ten circuits are, say, single-needle or double-plate sounder and the lower ten

A B C. Corresponding to these twenty indicators there are twenty switch-springs in the lower part of the case. The second and fourth rows have an additional switch-spring labelled "time" immediately to the left, which we shall consider later.

The twenty lines are brought from the test-box to the cross-connection strip. Each then proceeds to the lowest of the four springs of the switch-spring. Passing through the contacts of the latter the line leaves the upper spring and goes to its own indicator. The other side of this indicator, and of all the ten of this class of instrument, is then taken to earth through one of the switch-springs labelled "time."

One side of each working instrument is to earth and the other side connected by one conductor of a two-conductor flexible cord to the tip of a two-way peg. When this peg is inserted in a switch spring the instrument is put direct to the line, the indicator being cut out. Further, by means of the other conductor of the cord and the shank of the peg a press button, one of which is allotted to each instrument, is joined to the indicator, and when this button is depressed a local current is sent through the indicator, thus advising the switch operator that the line is clear so that he may sever the connection.

Each class of instrument has its own "time" spring. When an instrument peg is inserted in this hole all the lines are connected in multiple to it. This is for sending "time" to all stations.

A trembler bell and battery are connected to all the local circuits, together with a two-way switch, so that at night an audible call may be given.

Night and Sunday Concentration.—We have spoken hitherto of local circuits only. But it will easily be seen that it may be very convenient to include important main circuits as well, such as duplexes, &c. During working hours such circuits may be permanently pegged through to their respective instruments, but at night and on Sunday they can be treated as ordinary concentrated circuits. The instrument in daily use may be one of the switch sets, or it may be a separate one quite unconnected with the concentrator. In the latter case the line is brought from the test-box to a "plug key," and thence to the proper instrument. This plug key is a solid metal one and in its normal ("in") position connects the upper and lower springs. The upper inner spring is connected to an ordinary switch spring and indicator. When, therefore, it is desired to bring the line to the concentrator, the plug key is pulled forward. This action breaks the ordinary contact at this point and puts the line to the switch-spring and indicator. The normal instrument thus thrown out of use is then joined, by the same action, to a spare switch-spring and rendered available for any desired use.

Equalising Resistances.—When concentrating a number of circuits, since any one of them may be connected to any of the working instruments, it is necessary that the lines be of approximately equal resistance. If they are naturally unequal, resistance coils are added to level up. This added resistance is, of course, only required when the concentrator office is sending, hence the coil is fixed at the other terminal office, if a single needle between the two "bell" terminals. The battery power at the out station is then unaltered. If an intermediate station be on the circuit the battery power there must be increased, as the added resistance is in its sending circuit. In the case of a D.P.S. instrument this resistance coil is placed (at the out station) between one of the bell terminals on the commutator and the relay, in single-current sounder sets between the back terminal of key and relay, in double-current sets between middle back terminal of key and relay, and in duplex sets between the middle back key terminal and the duplex and single switch.

If the number of circuits be very large and the variation in their resistance also large, it may be better to bring them into two (or more) groups. That is one group of comparatively low resistance (all approximately the same, either naturally or by means of resistance coils) to be served by one voltage, and another group of higher resistance served by a higher voltage. In this case, of course, the working instruments supplied with one voltage will be confined to those circuits for which that voltage is suitable.

Mixed Up and Down Circuits.—Normally, the working sets will be either all up or all down and the terminal out stations correspondingly all down or up. But in the case of main line circuits it may not be convenient to make the out stations thus uniform. It may happen, too, that some of the out stations themselves may be on concentrators—some up and some down. To meet these cases the speaking sets are all provided with reversing switches, so as to be able to change from up to down at will.

Mixed Single- and Double-current Circuits.—In some cases, where only a small number of circuits are to be concentrated, some of such circuits being single-current sounder and others double current, an arrangement is set up by which all the speaking sets may be utilised on any circuit, single or double current indifferently. This is effected as shown in principle in Fig. 154. The switch springs of the double-current lines have one pole of a "spacing" battery joined to the upper spring, the other pole being to earth. The line is brought to the lowest spring and is connected to the indicator through the next spring. A three-way peg and cord is used with the working instruments. When a peg is inserted in the switch-spring the tip places the line in connection with the working set. Each set includes a specially modified S.C. key with switch and six terminals. When the switch is to the right the key offers a path to earth from the line spring, tip of peg, galvanometer, lever of key, relay, key switch to earth. When turned to the left this earth is

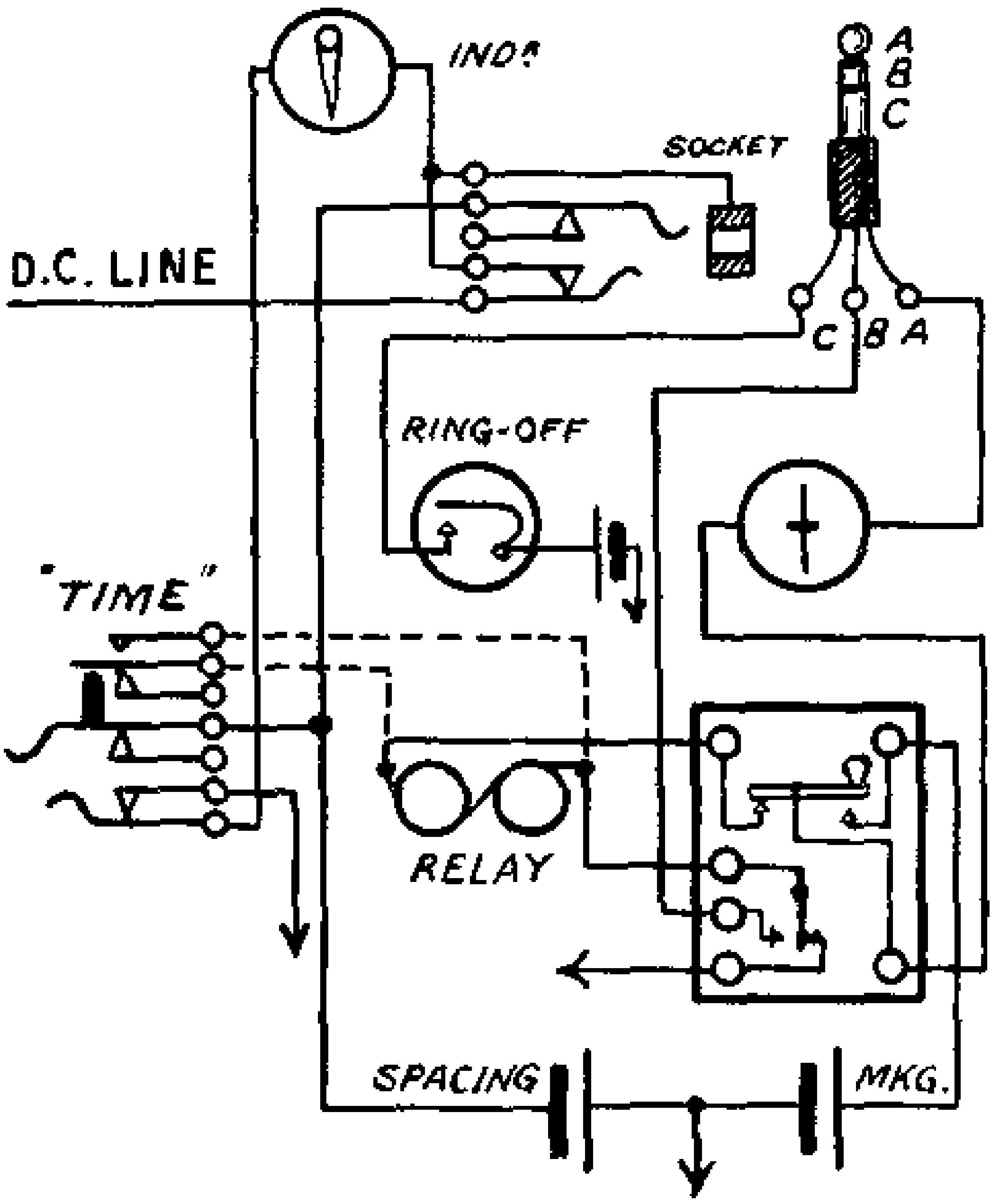


Fig. 154.—Concentrator: mixed single- and double-current circuits.

taken off and the spacing battery is brought to the key from the upper spring of the jack to the collar of the peg, the key switch, the relay, and thence to the back stop of the key. The ring-off signal is obtained by means of the shank of the peg and the switch-spring socket.

METROPOLITAN INTERCOMMUNICATION SYSTEM.

This system is the application of the concentration principle to the telegraphic business confined to the metropolitan area. Prior to its introduction a message, say, for Highgate, handed in at, say, Croydon, was sent to the central telegraph office and retransmitted to its destination. Instead of a transmitting centre the central office now acts simply as a huge concentrator, and puts Croydon in direct communication with Highgate, and so on.

The switchboard is divided into a number of sections, each of these being again divided into two parts, the "home" and "multiple" panels. In the latter are the switch-springs of all the lines brought to the switch, and beneath each switch-spring is an indicator to show whether the line is engaged or free. To the home panel is brought a certain number of the lines, terminating on a second set of switch-springs, together with the calling lamps. The number of lines thus brought to the home panel is such as to afford sufficient work for three operators.

On another section a further number of lines are brought to the home panel, and in the multiple panel all the offices on the switch are repeated, and so on with all the sections. Thus the lines are divided up amongst all the sections in the home panels, but in each multiple all the lines are repeated. When an office calls, its calling lamp immediately above the home switch-spring is lighted, and the operator inserts a peg into this switch-spring to learn what is required. Thus the calls from a certain number of offices are received and attended to on the home panels, and each of those offices can be put through to any other office on the system by means of the multiple panel above.

Fig. 155 shows diagrammatically the connections of one line upon the switch. The line is brought to the upper spring of the home and multiple switch-springs of its own section, and to the multiple springs of all the other sections. It is also

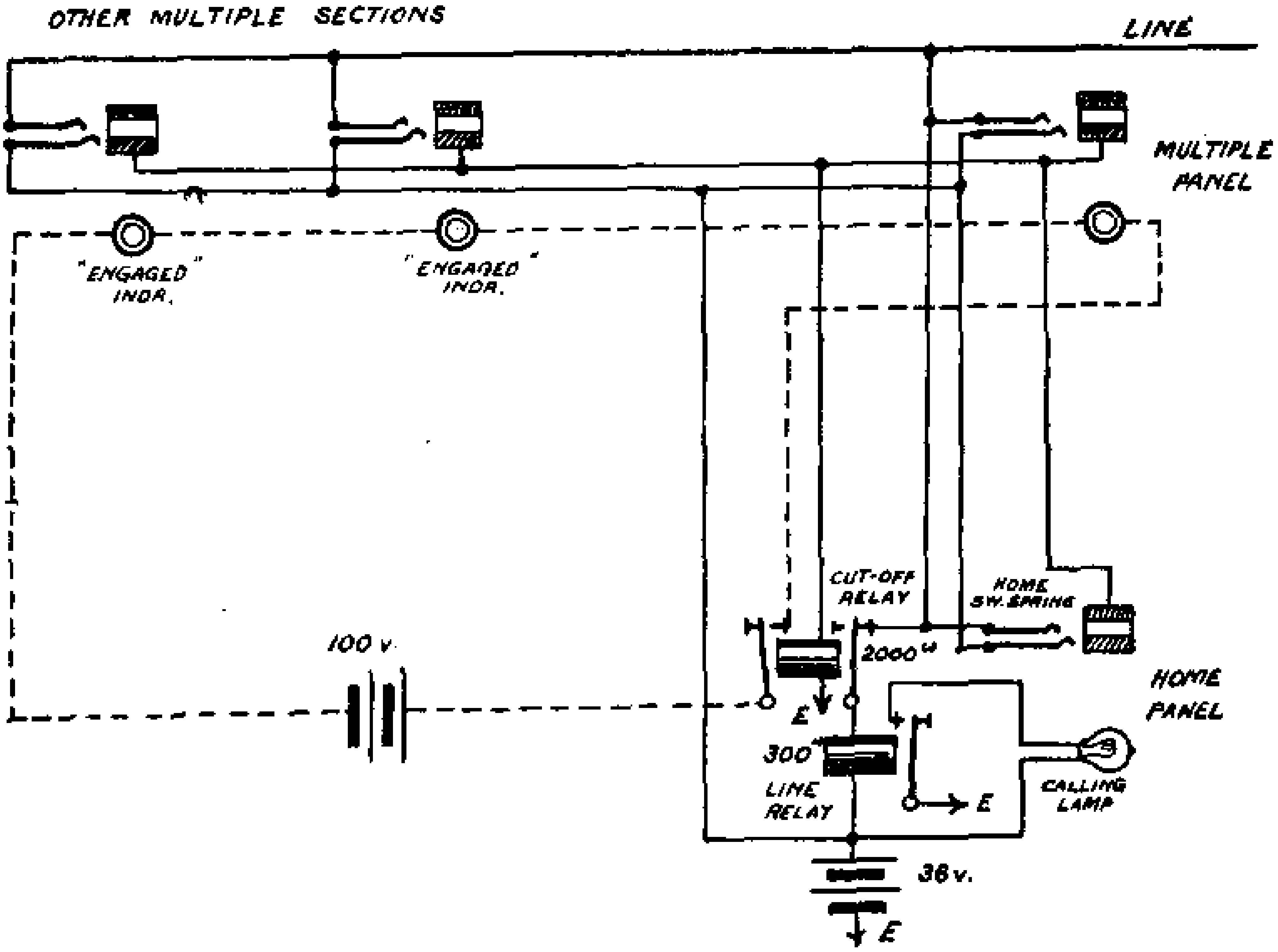


Fig. 155.—Switch connection of one circuit.

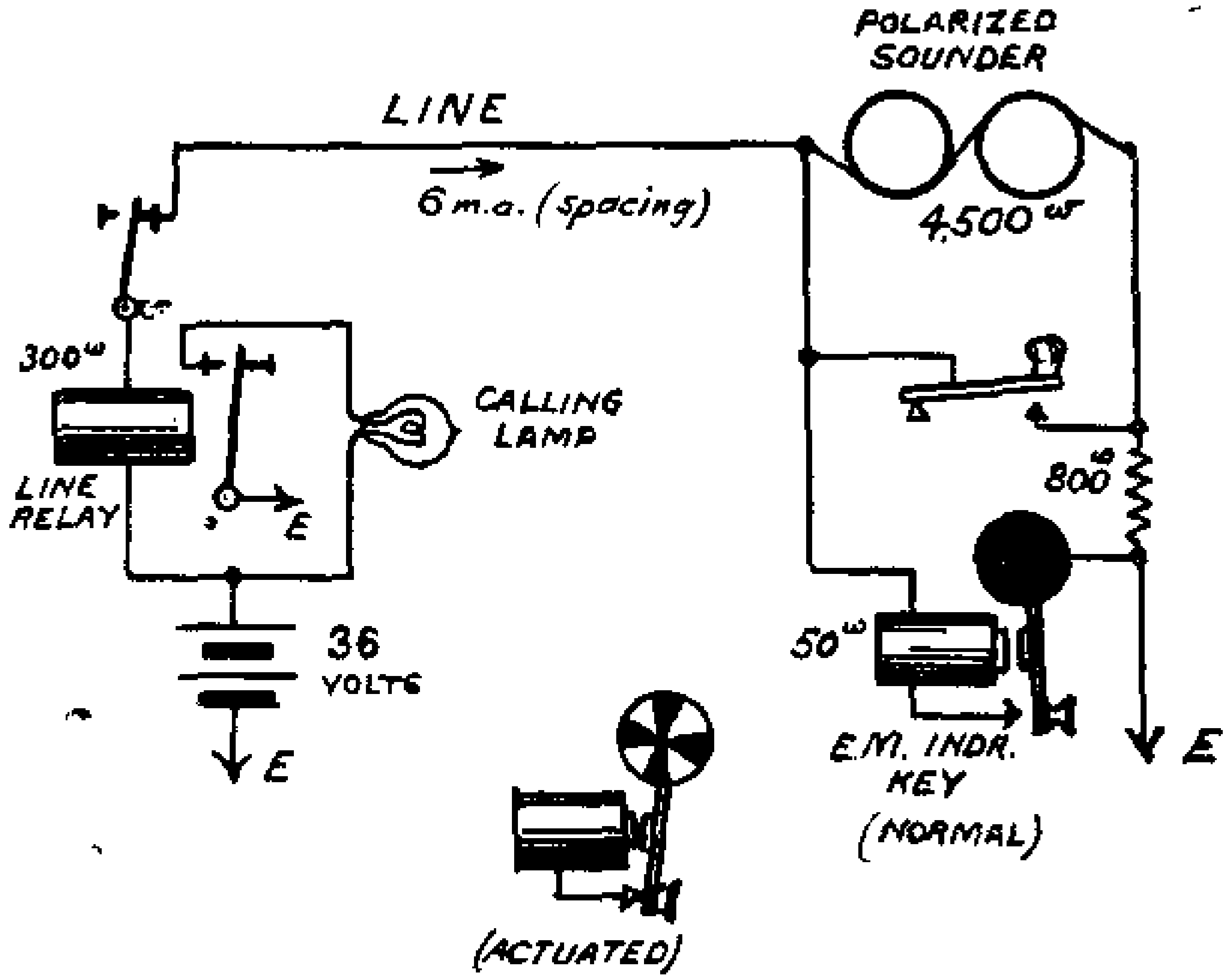


Fig. 156.

connected by one contact of the "cut-off" relay to the line or calling relay, whose local circuit includes the calling lamp. Fig. 156 shows the arrangement at the out office and the essential parts of the switch. At the out office is an ordinary single-current key, a polarized sounder of 4,500 ohms, an electromagnetic indicator key, and an 800-ohm resistance coil. These are joined up as shown on the right. The indicator key normally shows a black disc, but when its armature is moved over a disc of alternate black and white sectors is displayed. From the central office a current flows from the 36-volt battery through the line relay, line, polarized sounder, 800-ohm coil, and thence to earth. Its value is 6 m.a. and its direction spacing. The line relay is biased against it and is thus unaffected, whilst the polarized sounder is kept to spacing. If the Morse key be depressed the resistance of the out station will be reduced from 5,300 ohms (normal) to 800, whilst the depression of the plunger of the indicator key reduces the resistance to something less than 50 ohms.

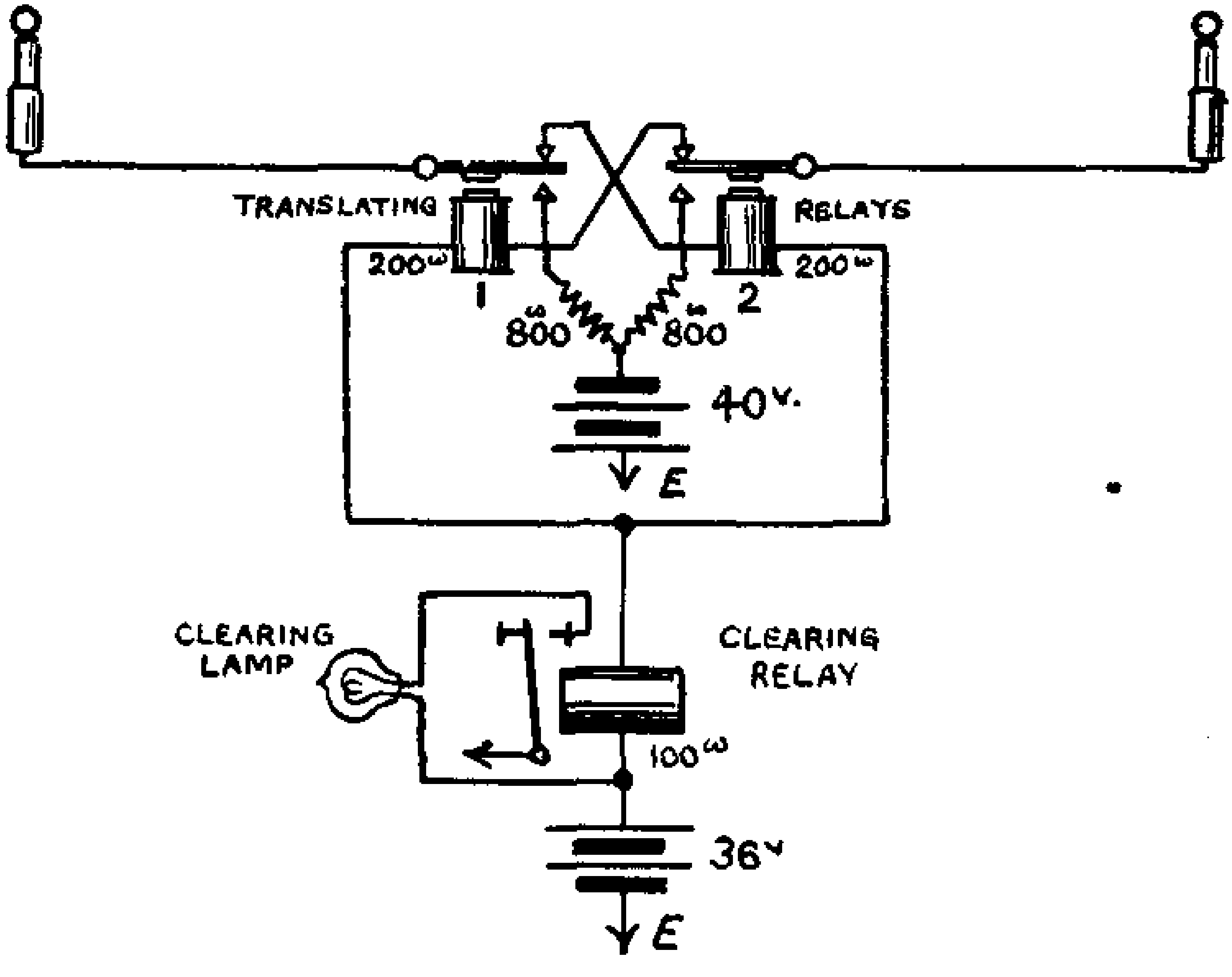


Fig. 157.—Cord circuit.

Now, suppose that the out office requires to be put through to another out office. He depresses his indicator key, reducing the resistance of his own apparatus and increasing the current to 65 m.a. This actuates the line relay and lights up the calling lamp at the central office.

The connections of a pair of pegs and cords are given in Fig. 157. Two (non-polarized) "translating" relays have their armatures connected to the tips of the pegs by a single cord. The pegs are really two-way, but only the tip is connected to the cord. When inserted in a switch-spring (Fig. 155) the tip connects the line to the armature of the translating relay, whilst the shank connects together the lower spring and socket.

On receipt of the call the operator inserts one peg of a pair into the home switch-spring. The act of putting in the peg causes a momentary disconnection of the line, thus allowing the armature of the indicator key at the calling office to be released, and to show black—indicating that the switch operator is replying. When the peg is inserted its tip is connected to the line, and the shank connects together the lower spring and socket of the jack. To the former is joined the positive pole of the 36-volt battery, and, to the latter, one side of the cut-off relay, whose other side is to earth (see Fig. 155). The connection being made by the shank of the peg, the contacts of the cut-off relay close, thus cutting off the line relay, whose calling lamp ceases to glow. The other lever of the cut-off relay closes the circuit of the engaged indicators, which are fixed beneath the switch-springs of the line in question in all the multiple panels of the switchboard. These are all actuated, and display a small white disc—otherwise invisible—thus indicating that the line is engaged.

Included in the cord circuit is a speaking key (not shown), which, when pulled over, brings in the operator's key, relay, and sounder, as shown in Fig. 158. A current of similar strength and direction to that flowing when the circuit is at normal (as in Fig. 156) now flows *via* the peg to line. The out-office then gives the number of the office required, all the offices on the system being identified by numbers instead of codes. If the desired line be free the switch operator puts the other peg into the required switch-spring on the multiple. The calling office then calls the other by his Morse key. The effect of the depression of this key is seen in Fig. 159. The resistance is reduced to 800 ohms, and the current increased from 6 m.a. to 27. This actuates the right-hand translating relay, whose armature then sends (or repeats) from the negative pole of the 40-volt battery. This gives the same value (6 m.a.) in the right-hand line, but is marking in direction. The office required replies on his Morse key, and the stations are "through."

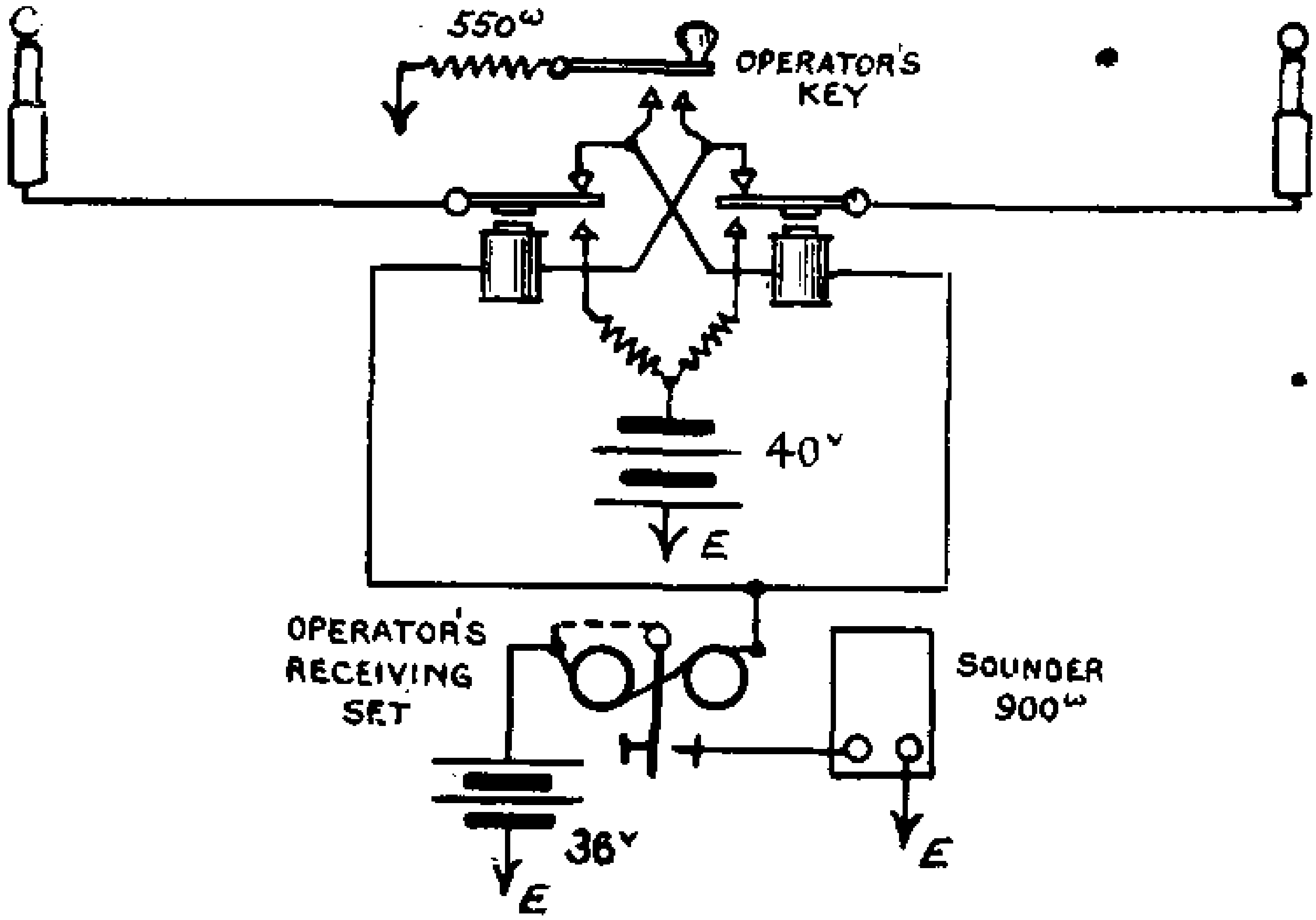


Fig. 158.—Cord circuit: switch "speaking."

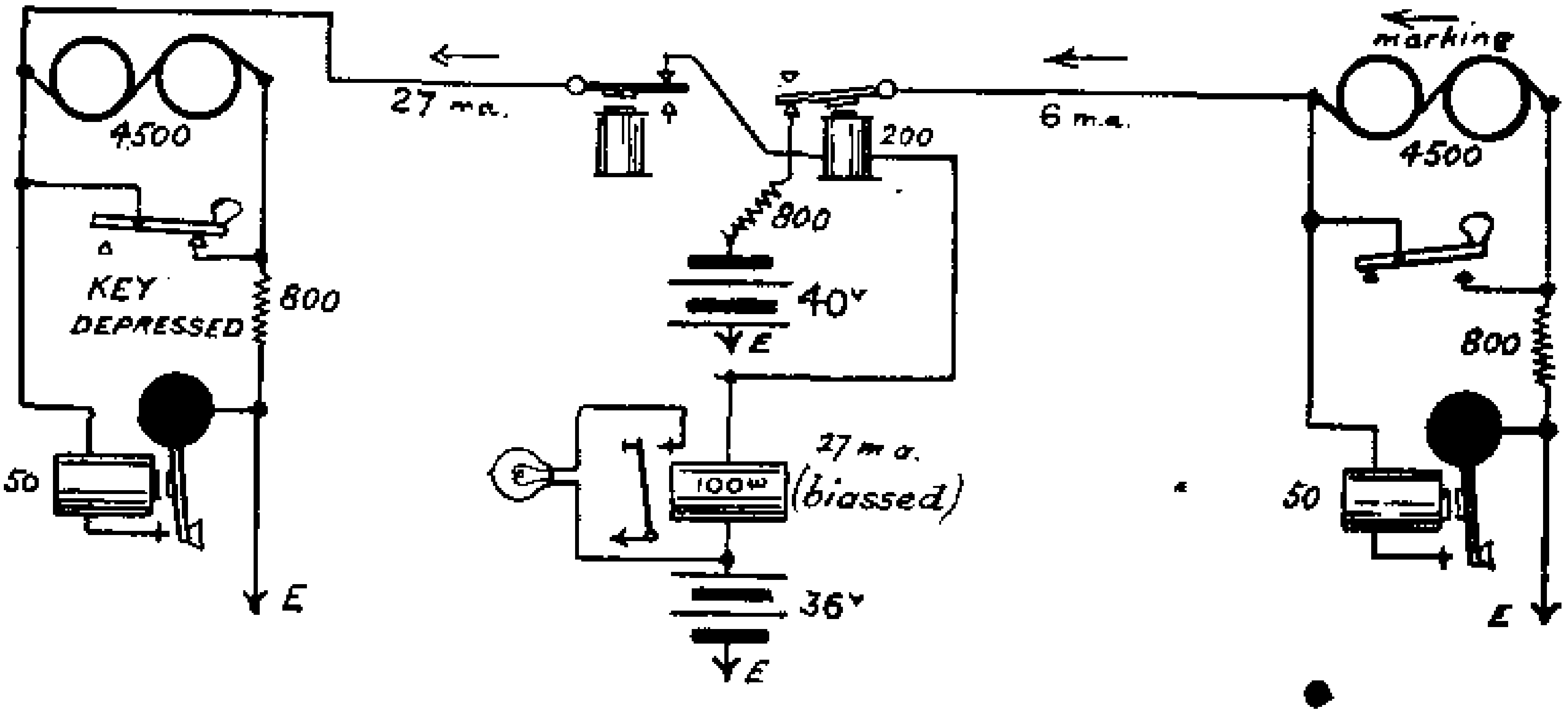


Fig. 159.

It will be seen that the sending office simply increases the current in his own line by the depression of his key, and actuates the opposite translating relay. The other line is worked double-current, the spacing current coming from the 36-volt battery and the marking from the 40-volt by the movement of the relay armature. Its value in both cases is 6 m.a.

When the two offices have finished they depress their indicator keys. Assuming that the right-hand office has done this first, the state of affairs shown in Fig. 160 results. The current in the right-hand line is increased to 65 m.a., which actuates the clearing relay and the left-hand translating relay. The other indicator key being also depressed the current in its line is 38 m.a., from the 40-volt battery. Both indicator keys thus show the star, as in Fig. 160. When the operator clears, the momentary disconnection occurring in the withdrawal of the pegs releases the indicator keys, and restores them to normal. Each office is thus aware that the connection is severed.

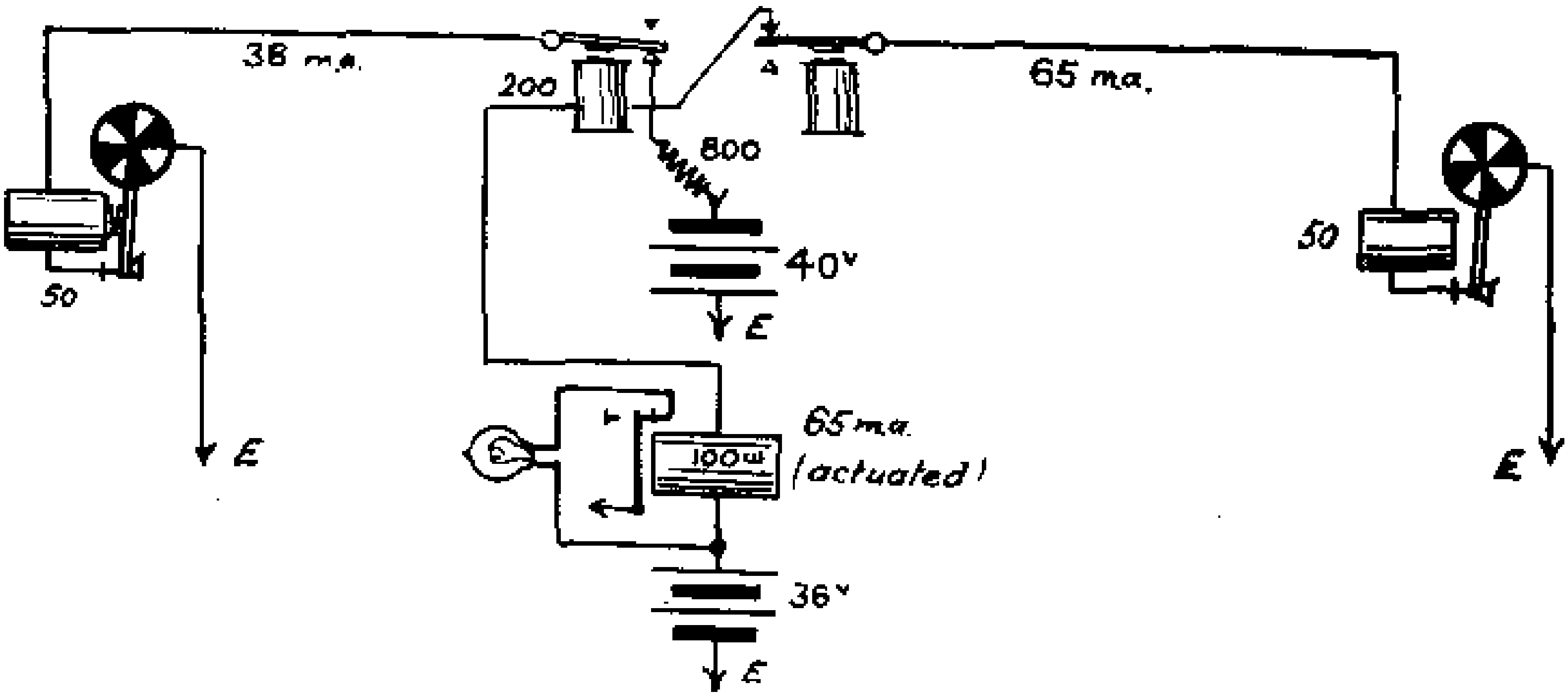


Fig. 160.—"Clearing."

In the case of an office having provincial or foreign messages connection with another switch-office is, of course, not required. In such a case the office calls the switch, not by depressing his indicator key—which gives a continuous glow on the calling lamp—but by repeating, on his Morse key, the ordinary call T S. The switch operator sees this, and pegs the office through to a working set, on which the message is received and put in the proper channel for circulation. These working sets are connected up to positions on the multiple panels just as the ordinary lines are.

Central Battery System.

One of the great features of the intercommunication scheme is the absence of all batteries from the out stations—the battery-power all being supplied from the central office itself. The advantages of such a plan are obvious.

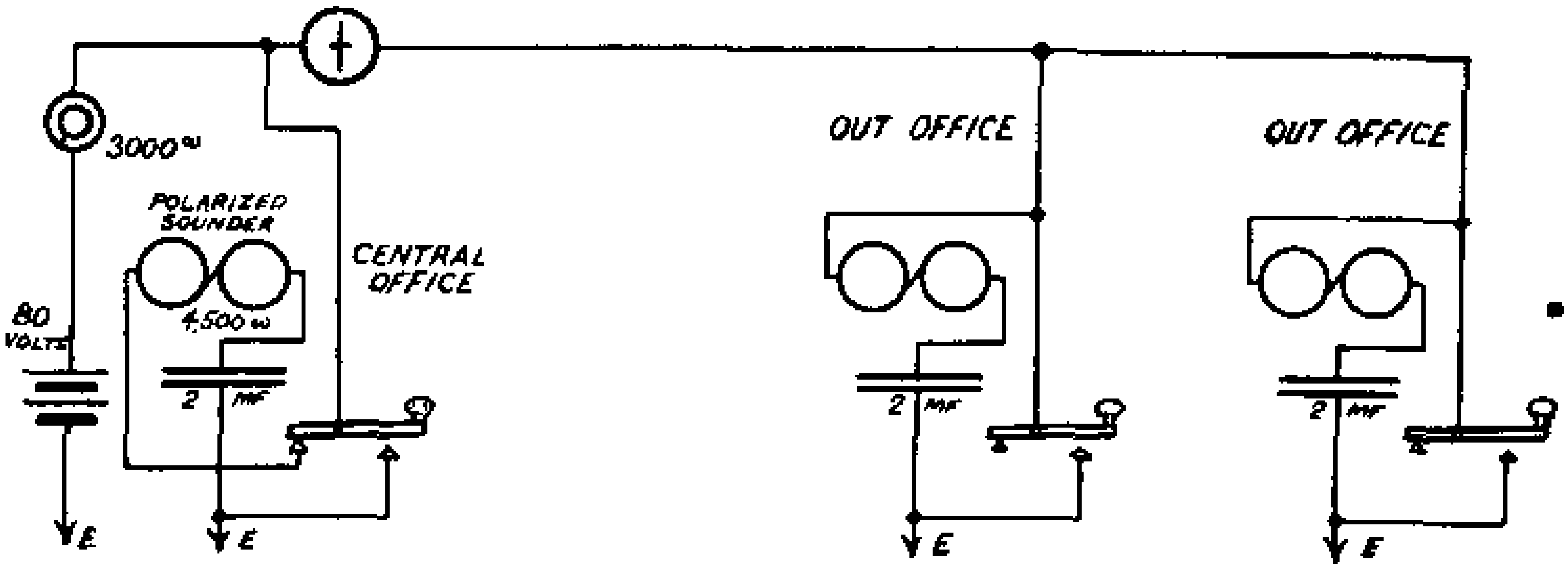


Fig. 161.

Fig. 161 shows the central battery principle applied to an ordinary circuit with two out offices. Each of the latter is fitted with a polarized sounder, single-current key, and 2-m.f. condenser. At the central office a galvanometer is added, and the battery is applied through a resistance (a bridging coil) of 3,000 ohms. In the normal state, as in the diagram, the line side of all the condensers is charged up to 80 volts, positive. When the central office depresses his key he earths the line at the junction near the galvanometer. The charge in the out station condensers then passes through the polarized sounders, causing their armatures to move to marking. When the central office key

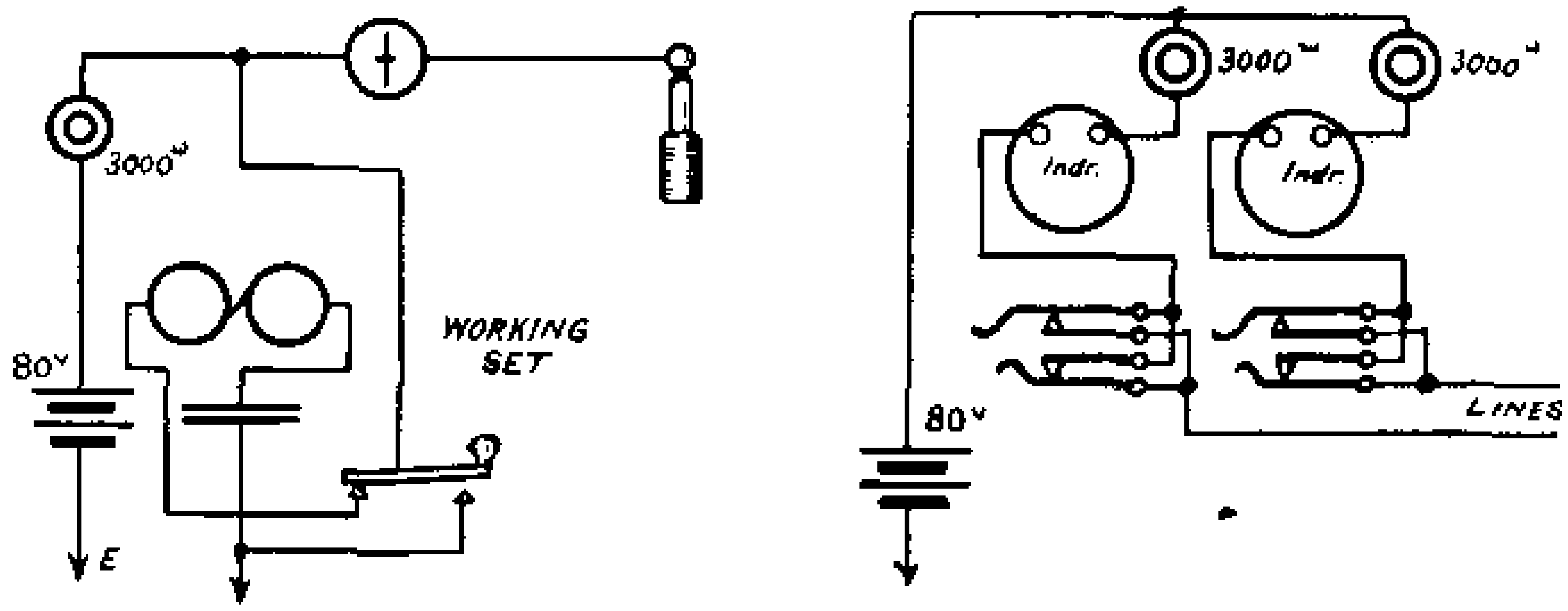


Fig. 162.

falls back to normal, the battery is again applied to the condensers, and the impulse charging them moves the polarized sounders to spacing. When either out station depresses his key he puts earth on the line side of the condensers—including his own. The condensers thus discharge through the polarized sounders, and affect them in a marking sense. When the key returns to rest, the battery again charges the condensers, the charge causing all the sounders to move to spacing.

Fig. 162 shows the same principle applied to the ordinary concentrator.

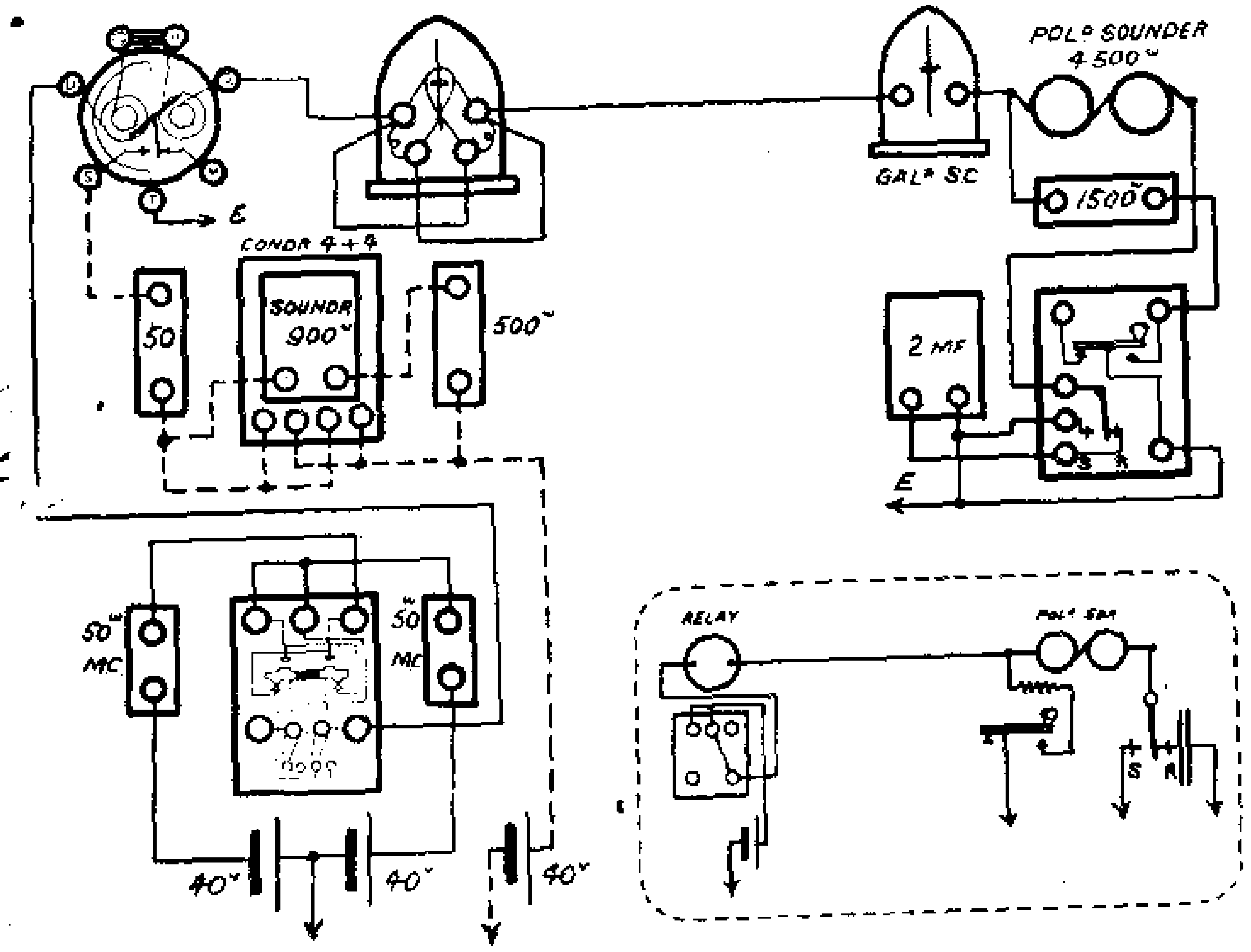


Fig. 163.—Central battery system: duplex or single.

Central Battery Duplex.—Fig. 163 shows a circuit arranged for duplex or single with battery at the main office only. At the latter office a non-polarized relay is in use, with its local circuit arranged as on the quadruplex B side, whilst, at the out station, a single-current key is employed with six terminals and switch.

The inset in the right-hand lower corner gives the skeleton connections for simplex. At both offices the key switches are normally to "receive." In order to send, the out station has simply to manipulate his key, without altering his switch. When the key is depressed, a path to earth of 1,500 ohms is opened to the central office battery. This results in a current of sufficient strength to actuate the relay, and with it the sounder. When the central office sends, he turns his key-switch, and the distant polarized sounder is worked by the impulses sent into its own condenser, these impulses being insufficient to actuate the relay at the central office.

When duplex working is desired, both key-switches are turned to send. A spacing current then flows from the battery, through the home relay (its strength being insufficient to actuate the latter), and the distant polarized sounder. When the key at the central office is depressed, this current is reversed, causing the out-office sounder to "mark." When the distant station puts down his key, he reduces the resistance of his apparatus to one-quarter. The current is increased to (roughly) four times its former value, and this, irrespective of its direction, actuates the central-office relay. The resistance of the polarized sounder to that of the new path opened by the depression of the key, is as 3 : 1. Hence only one-fourth of the increased current passe through the sounder, and this value is equivalent to the tot value of the original current. Hence the current passing through the polarized sounder is unaltered by the working of its own key.

The reversal of the central office key causes a break in its received signals, hence the arrangement of the local circuit.

CHAPTER XII.

REPEATERS.

As we have already said, the great aim is to get the maximum speed of working from a telegraph line. The rate of hand-working is far below the carrying capacity of even a long line, and the adoption of automatic working results in the attainment of much higher speeds. The speed—generally considered from the automatic standpoint—of a long circuit is naturally less than that of a short one. Taking the case of London and the Scottish centres, we can arrange London-Leeds and Leeds-Glasgow circuits. London can then send his Glasgow work to Leeds, have it received, deciphered, and written down there, and then re-transmitted from Leeds to Glasgow. If, however, we can work direct from London to Glasgow, we shall save the labour of the transmission at Leeds; but the direct line cannot be worked at the same speed as either of the shorter sections. By introducing a repeater at Leeds, however, we secure the advantages of direct working, and the speed of the circuit will become practically that of the slower of the sections.

The rate at which signals can be propagated through a wire depends upon the resistance and the capacity of the latter. If we halve its resistance it will work at twice the speed; similarly, if we halve its capacity, we double the speed; if we do both—*i.e.*, halve the capacity and halve the resistance—we shall be able to work the line at four times the original speed; that is, always assuming that we have not reached the limit of either line or instruments. Now, both resistance and capacity increase directly with the length of wire used; hence, it follows that the speed of a circuit varies inversely as the square of its length. If, therefore, we cut up a long line into two equal sections by the introduction of a repeater, then—subject to the limitations mentioned—we should increase its working speed fourfold.

Evolution of Repeater.—In ordinary working, the line current, on reaching the receiving station, passes through and actuates the relay, which, in its turn, works the sounder or local inker, as shown, in the first case, in Fig. 164. If the E.M.F. of the local battery be suitably increased and the relay tongue be joined, not to a local circuit, but to another length of line, the movements of the tongue will send to the extended line currents of practically the same length and direction as those which actuate the relay. These "repeated" currents, arriving at the distant station, cause the latter's receiving apparatus to respond. Thus, the movements of the key at Y, in the second case, of Fig. 164, are faithfully reproduced on the sounder at X by means of the repeater at R. The relay tongue and contacts at R, indeed, become a second single-current key under the control of station Y.

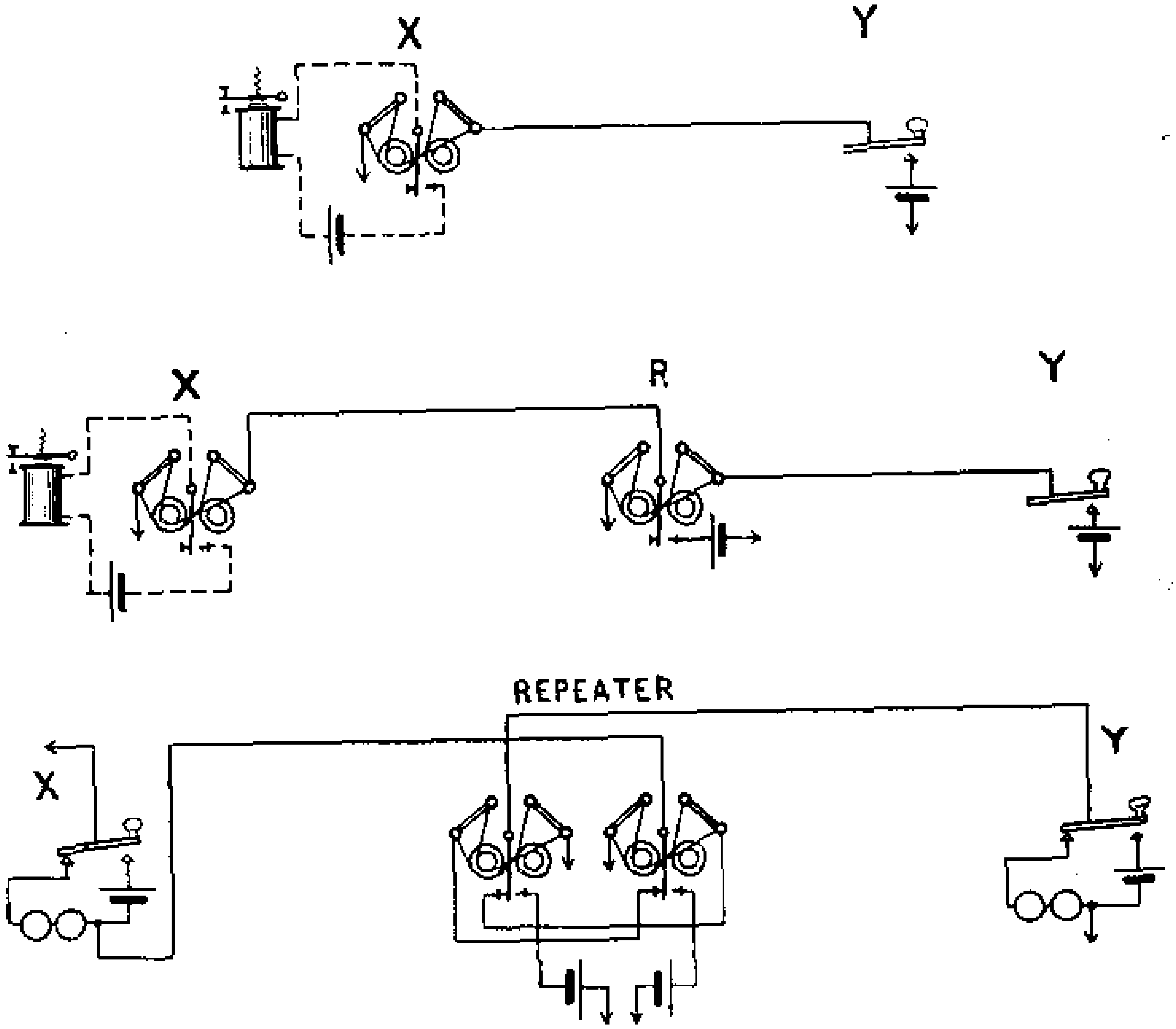


Fig. 164.—Evolution of repeater.

But we need to work both ways; two relays, thus, are necessary, one to be actuated by currents from the up, and the other by currents from the down, station. This is shown in the remaining case at the foot of Fig. 164. The two relays, thus arranged, constitute a "repeater" in its simplest form. The two lines are brought to the tongues, whilst the spacing stop of each relay is connected to the coils of its neighbour, and thence to earth. When the up station sends, his current passes through the tongue and spacing stop of the left-hand relay, and through the coils of the right-hand one. The tongue of the latter then moves to marking, and repeats a similar current on to the down line. The signals from the down station traverse the tongue and spacing contact of the right and the coils of the left-hand relay. The tongue of the latter is actuated, and repeats the current to the up station.

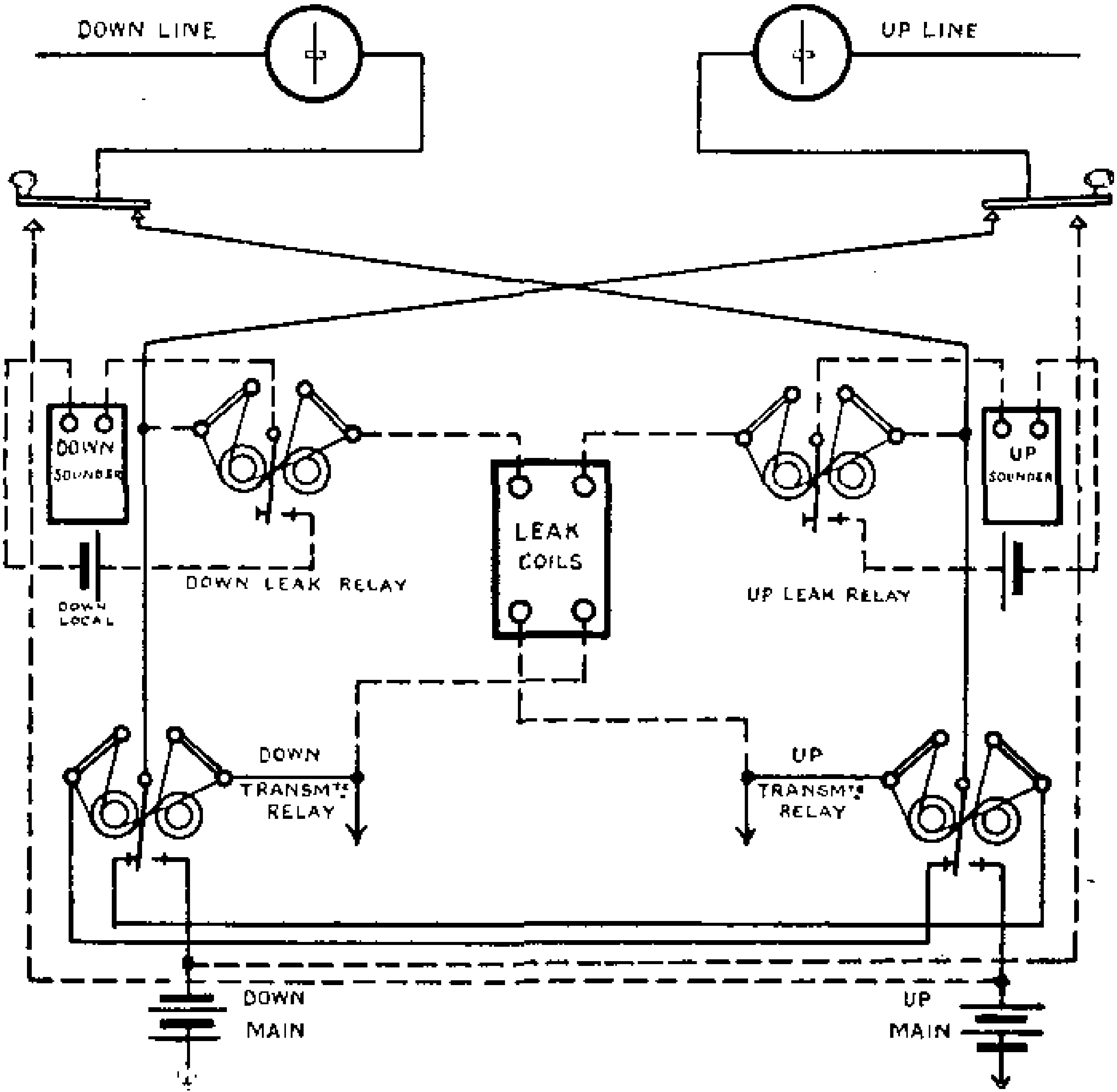


Fig. 165—Simple repeater.

Simple Repeater.—For a practical repeater much more apparatus is, of course, necessary. The operator at the repeating station must be able to see that the currents are passing properly —*i.e.*, that the repeater is doing its work. He also requires the means of readily communicating with either or both terminal stations. The necessary arrangements for this are shown in skeleton form in Fig. 165. The relays, whose function it is to repeat, are termed the "transmitting" relays. The tongue of each of these is connected not only to the line, but to a "leak" relay, the other end of whose coils is joined to a high resistance, and thence to earth. The contacts of this relay are connected up, with the necessary local battery, to a sounder. When the tongue of the transmitting instrument moves to the marking stop, it, therefore, sends not only to the line, but also through this leak circuit. The sounder therein included thus indicates what is being repeated to the other line. A galvanometer is also inserted in each line, and a key, to enable the repeater station to speak with the terminal offices.

When, say, the up station sends, the current arrives through the up galvanometer, passes *via* the key to the tongue of the down transmitting relay, through the spacing contact, and thence to earth *via* the coils of the up transmitting relay. The tongue of the latter moves to marking, and sends a current from the up main battery through the key and down galvanometer to the down line, and also through the up leak, thus working the up leak relay and sounder. The up galvanometer thus shows the received current and the down the repeated current—the working of the up sounder enabling the repeater station to distinguish between them. If the down station were sending, of course, all these operations would occur on the other side of the apparatus.

It will be seen, also, that the received current, on arriving at the tongue, say, of the down relay, has the down leak circuit in multiple with the coils of the up relay. Owing to the very high resistance of the former path, very little current passes that way; but what does pass is in a spacing direction as regards the leak relay, so that the latter is unaffected.

Duplex Repeater.—The principle of a (differential) duplex repeater is indicated in simple outline in Fig. 166. The coils of the two transmitting relays are necessarily placed in series and the tongue of each relay connected to the split of the coils of its neighbour.

The current from the up line passes through the right-hand coils of galvanometer and relay on the up side, thence to the tongue of the down relay and then to earth through *r*, a resistance approximately equal to that of the down main battery. The tongue of the up relay is thus moved to the right and sends a current from the up main. This current splits at the strap of the down relay, half going to the down line and half through the rheostat R, in which is suitable resistance, and attached to which is suitable capacity to balance the resistance and capacity of the cable. The down relay and galvanometer coils are thus traversed by equal currents in opposite directions and are, therefore, unaffected.

When both stations are sending, the currents are augmented in the line coils of the galvanometers and relays and consequently predominate over those in the compensating coils. This excess actuates the instruments: the two relay tongues going to "marking," and the galvanometer needles being deflected to the left.

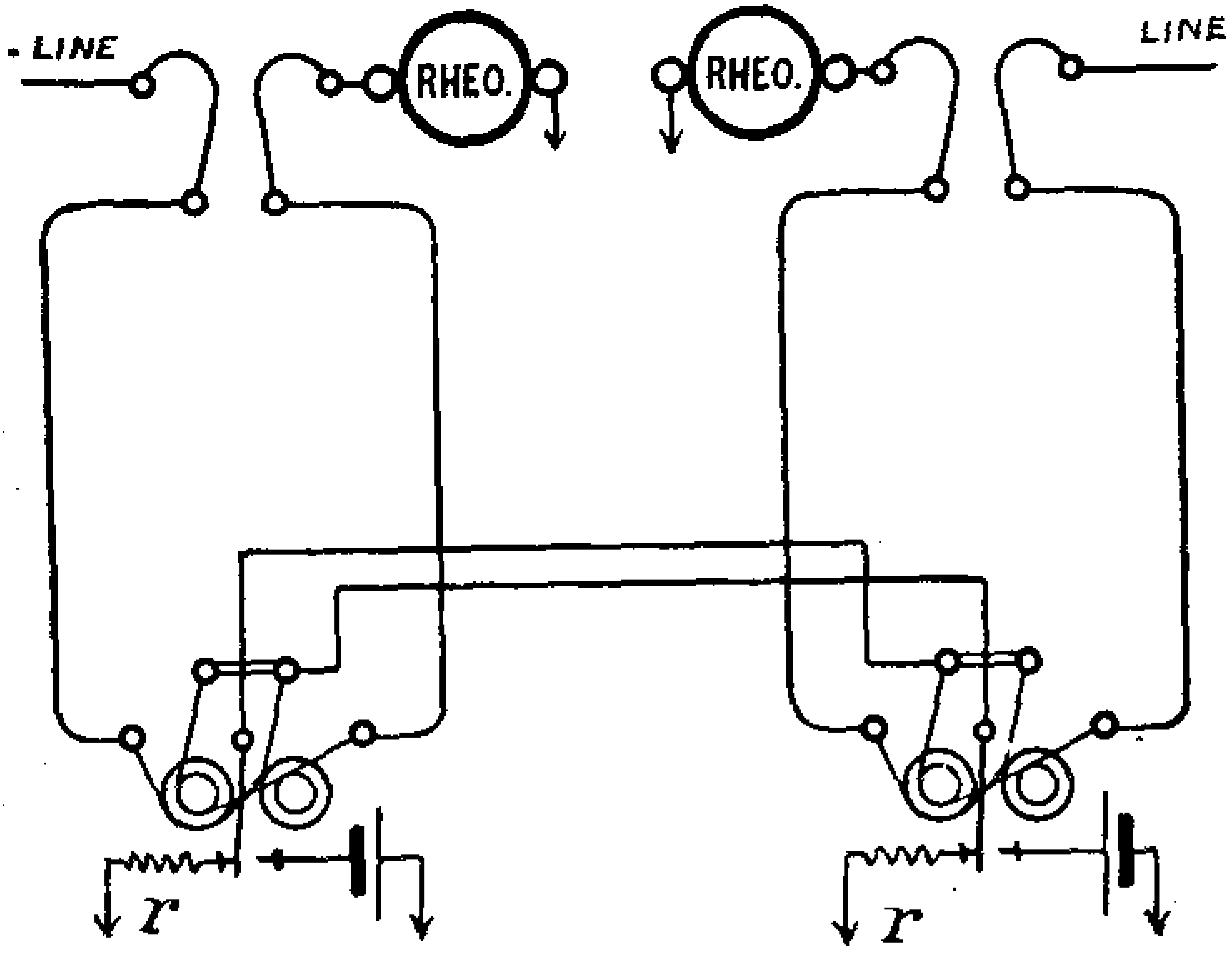


Fig. 166.—Duplexing of repeater.

Fig. 167 gives further details as seen from one side of the repeater, omitting some on the other. When the down relay tongue moves to marking, the sent-out current first splits at the leak and key—a small portion going to work the leak relay. The main current then goes on to the strap of the up transmitting relay, dividing into equal portions there, as already described.

Double-current duplex working will also be easily understood from Fig. 166. An additional battery is brought to the spacing stop of each relay, so that whatever the position of the tongues a battery is always in use. With both terminal keys depressed

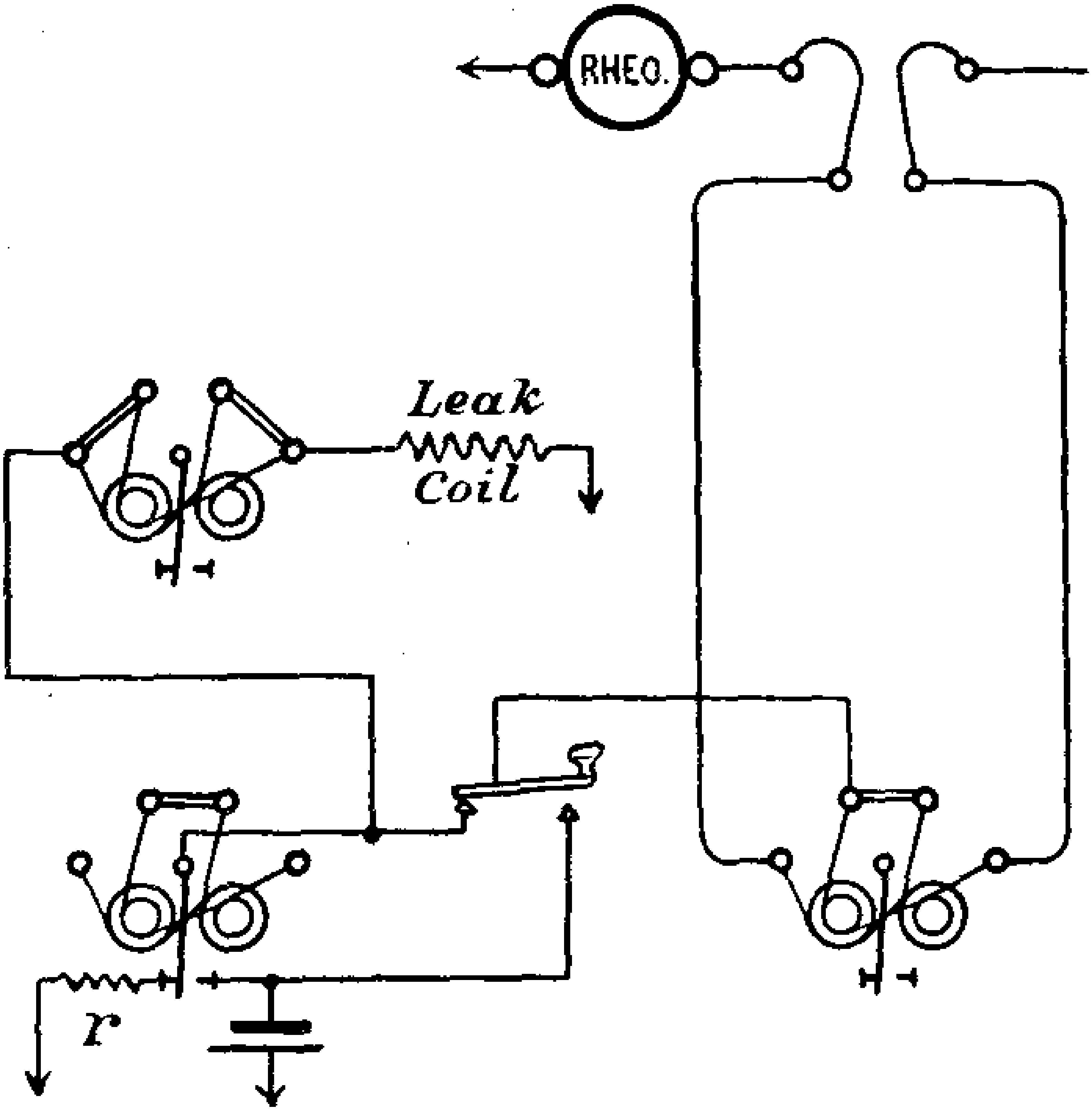


Fig. 167.

we have precisely similar conditions to those in single-current duplex. With both keys at rest we have the same, but the direction of the currents is everywhere reversed: the relays are kept to spacing and the galvanometer needles are deflected to the right. With one key depressed and the other at rest the repeater and terminal batteries oppose each other in both lines so that no currents flow there. The transmitting relays, like the relays at the terminal stations, are then worked by the compensating currents.

Double-current Repeater.—We have considered a double-current *duplex* repeater because it is actually a simpler arrangement than a double-current simplex repeater as there is no need for the automatic switch. This is the piece of apparatus corresponding to the "send and receive" switch on the double-current key. It is illustrated in Fig. 168. Two bar electro-magnets are laid side by side, and at each end of the system thus formed is a soft iron armature carrying an upright brass arm or lever. The lower part of this combination of armature and lever is mounted on pivots and the upper part is movable between two contacts. It is kept off the poles of the electro-magnet by an adjustable spiral spring, thus normally making contact with the outer stop. When the armature is attracted the lever moves forward to the inner stop. Thus we have two movable levers, each playing between two contacts. When at rest both levers are connected to the outer contacts of the instrument. When a current passes through the coils both armatures are attracted and the levers make contact with the inner stops. The two latter are generally connected by a brass strap. The coils are wound to 60 ohms and a shunt of equal resistance is placed across them, thus reducing the effective resistance to 30 ohms. The function of this low-resistance shunt is to provide a path for the free circulation of the extra current from the coils, thus prolonging the magnetic effect for a sensible period after the

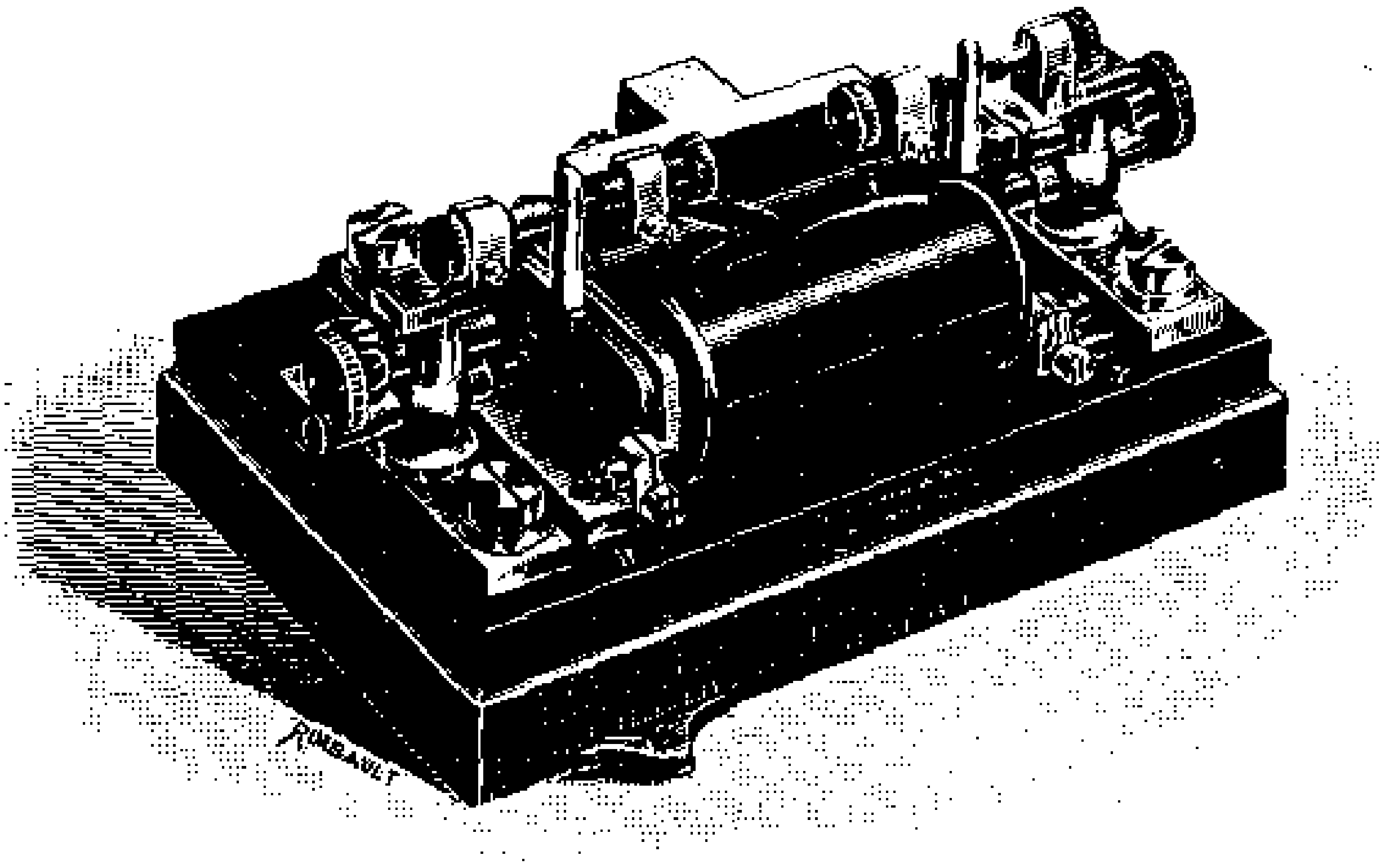


Fig. 168.—Automatic (electro-magnetic) switch.

current proper has ceased. The arrangement is precisely similar to that of the relaying sounder previously considered—only in this case the large iron cores give a much greater effect. The coils of the switch are connected on the one side to the tongue, and on the other to both the marking and spacing stops of a neutral relay. A current in either direction through the coils of the latter, by moving the tongue to the right or left, causes the closing of the local circuit, and by means of the local battery the switch is actuated. Assuming that a succession of reversals is passing through the neutral relay, causing the tongue to vibrate between the marking and spacing stops, the self-induction of the switch prevents the release of the levers at the break which occurs when the tongue is crossing from one side to the other.

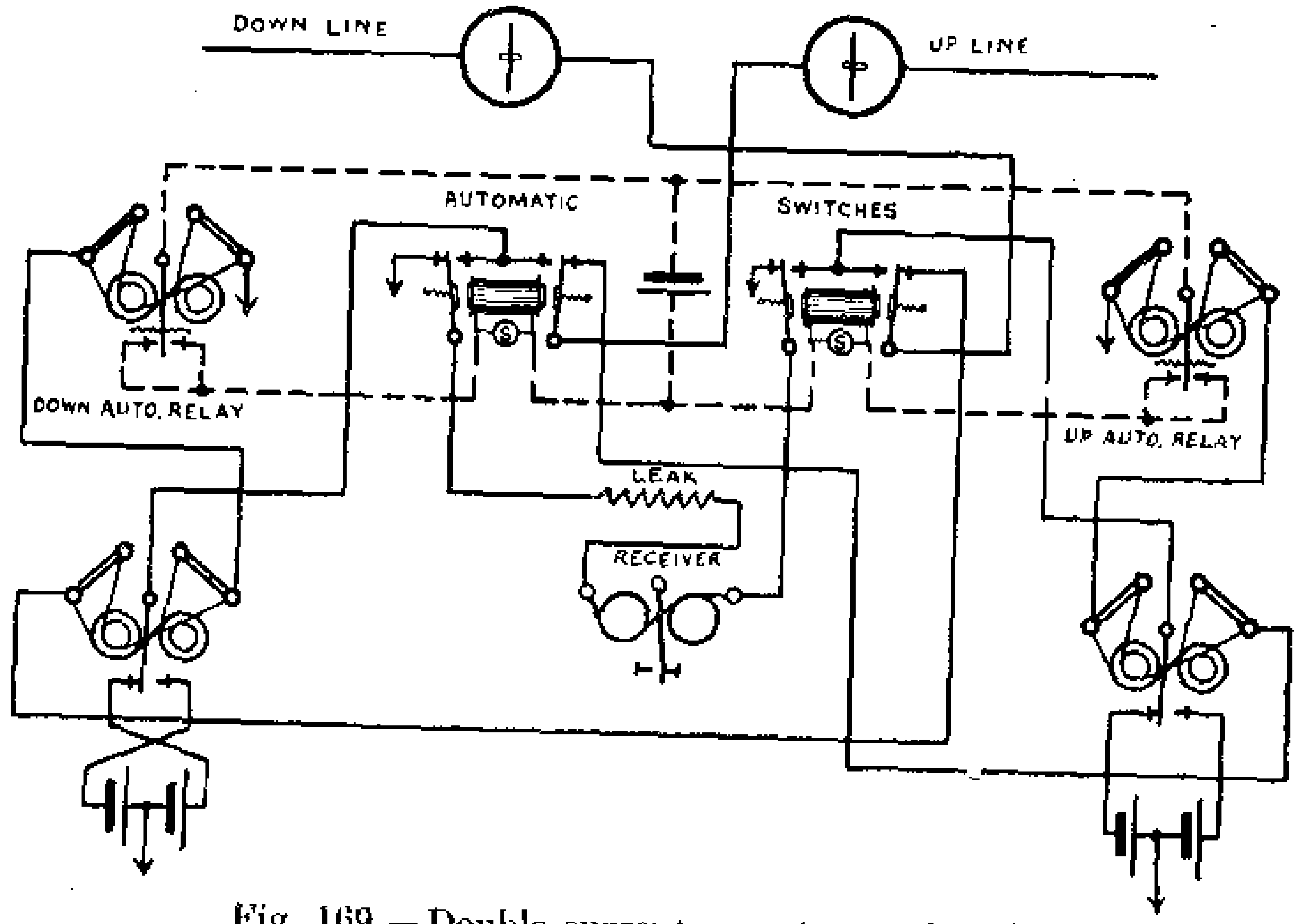


Fig. 169.—Double-current repeater : principle.

Fig. 169 shows the theoretical connections of a repeater arranged for double-current working. The lines, instead of being connected to the tongues of the relays, are brought to the right-hand levers of two automatic switches, and the back contacts of these are joined to the coils of the transmitting relays and through these to the coils of the switch relays. The main relay tongues are brought to the central contacts of the switches, and the ends of the single leak circuit to the left-hand levers.

whose back stops are to earth. Hence when either switch is actuated the levers put the main battery in connection with the line and leak—the direction of the current depending upon the position of the main relay tongue.

Now, let us suppose that the switch at the up station is to "send," and that the key is depressed. A "copper" current arrives at the repeater, passes through the up galvanometer, through the right-hand lever of the switch on the down side of board, thence to terminal (U) of the up transmitting relay, through the coils—causing the tongue to go to marking—to the up neutral relay and to earth. The tongue of the latter relay likewise goes to marking, and completes the circuit of the automatic switch on the right of the board. The switch-levers, *accordingly, move inwards. The tongue of the up main* relay being to marking (as already seen), a "copper" current passes thence to the centre contacts of the switch and splits there, part going through the down galvanometer to the down line, and part through the leak receiver, leak coil, and to earth through the left-hand lever of the switch on the down side. When the up station finishes sending he turns his switch to "received," thus cutting off the current. The levers of the up side automatic switch then fall back, and the apparatus is ready for the down station to send.

HUGHES REPEATERS.

Repeaters of the simple single-current type are used exclusively on the London-Continental Hughes circuits. As we have seen, the Hughes is a single-current system—all the signals consisting *of currents of the same length, separated by differing intervals* of time. By means of several such repeaters, very long circuits are worked direct. Thus London works to Rome, with repeaters at Paris and Lyons, and to Vienna, with repeaters at Lowestoft, Emden, and Erfurt. Such a repeater is shown in diagram, Fig. 170.

As to the apparatus involved:—The four relays are of the usual standard type, as are also the two differential galvanometers—the coils of the latter being joined in parallel. The six-terminal switch has two positions, labelled D F and I Q. In the former, "direct line free," the relay tongues are in communication with the lines, for the purpose of repeating. When turned to IQ, the tongues are cut off from the lines, but not from the leaks. Hence the transmitting relays do not then repeat the arriving signals. This switch is for use when the repeater office is speaking with the terminal stations, or with another repeater station. The switch shown between the two galvanometers has three positions. When the lever is central, as in the diagram, both up and down batteries are brought to the marking stops of the transmitting relays. When turned to the left, the down battery is cut off, but the up remains on. Similarly, when turned to the right, the up battery (only) is cut off. The batteries are permanently connected to the keys, which are of the usual single-current type.

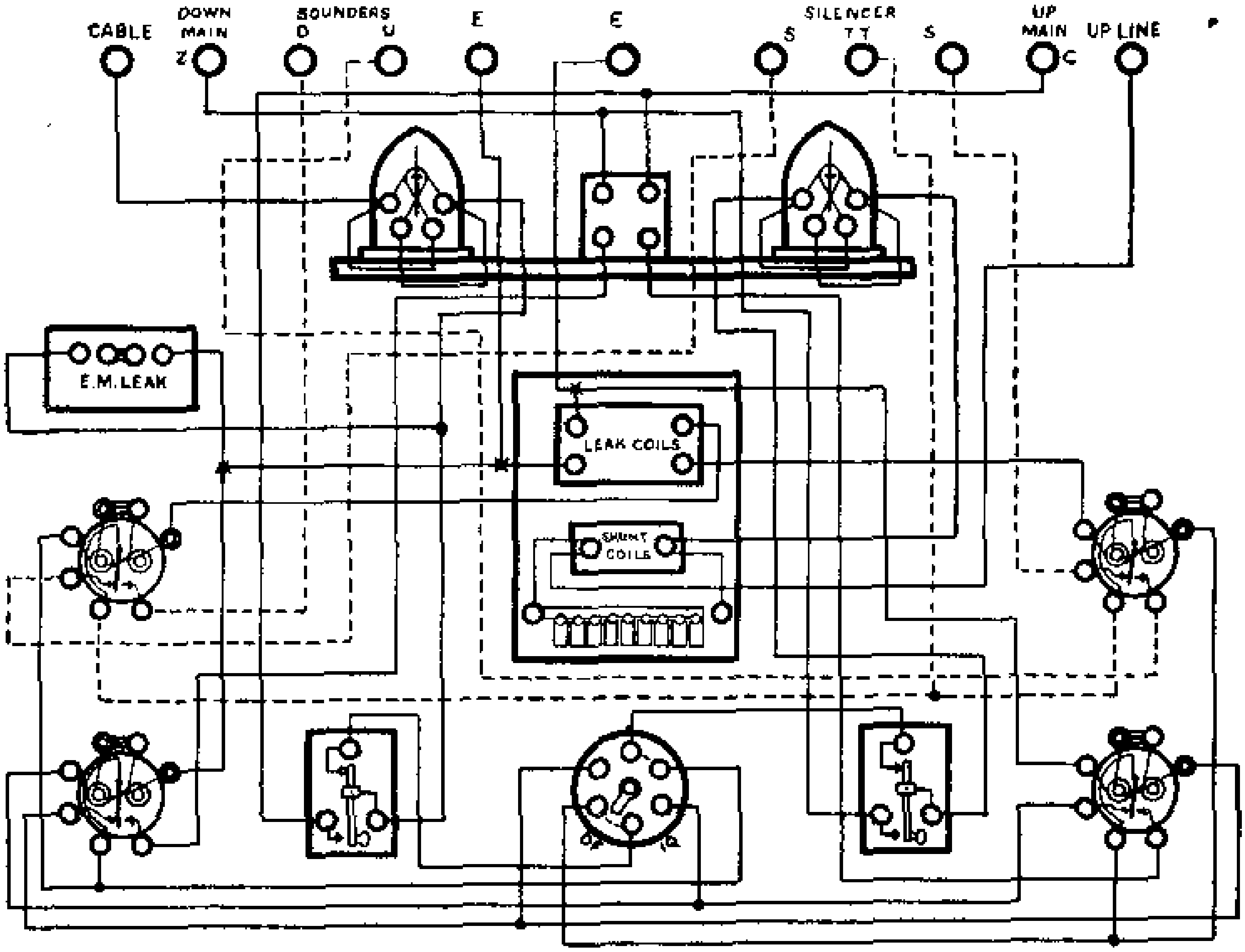


Fig. 170.—Hughes repeater: single.

The land line (to London, who is the up station) is brought to the extreme right-hand terminal of the board, and the cable to the left.

The condenser of 10·25 microfarads (adjustable) and its shunt are also included in the up receiving circuit. The shunt has four coils of each, and these are all normally cut out. The object in placing the condenser and these coils in this position is to provide a means of working by condenser on the land side, when earth currents are prevalent. All that is required to insert the condenser is to withdraw the necessary plugs from the shunt. The capacity, having once been set, need not be disturbed.

The leak coils are combined to form one instrument. Each set has four coils of $5,000^{\omega}$ each, and three plugs and holes. One coil in each is therefore permanently in circuit, and cannot be plugged out. The usual resistance employed is $10,000^{\omega}$ or $15,000^{\omega}$.

Neutralization of Cable Discharge.—This is the function of the electro-magnetic leak seen to the left in the diagram. This has two cores similar to the arrangement of the standard relay, but a soft iron armature is permanently fixed across their upper ends, and another across the lower, thus forming a closed magnetic circuit. The cores proper are wound differentially, and the wires brought to four terminals on the top of the box, and straps are provided for joining the coils as desired. Each coil having a resistance of 500^{ω}, the two joined in series give $1,000^{\omega}$. The winding being precisely the same as for an electro-magnet—that is, not loop wound as in the ordinary resistance coil—and, having a complete circuit of iron, the instrument has large self-induction.

Now, one of the effects of the capacity of the cable is the following:—At the cessation of every signal sent into it, a portion of the charge returns to find earth at the sending end. That is, when the tongue of the up relay returns to its spacing stop, a portion of the positive charge communicated to the cable returns and goes to earth through the coils of the down transmitting relay. It passes through the latter in a spacing direction; hence the tongue is not moved, but the continued discharge through the coils of the relay tend to polarize the latter in a certain direction. It is, therefore, very desirable to get rid of this discharge. One end of the electro-magnetic leak is connected to the cable (on the inner side of the galvanometer), and the other end to earth. Every signal sent into the cable is, therefore, accompanied by one sent into this leak. When the tongue returns to spacing, the discharge from the cable is met by the extra current from the coil, and, as the two discharges are

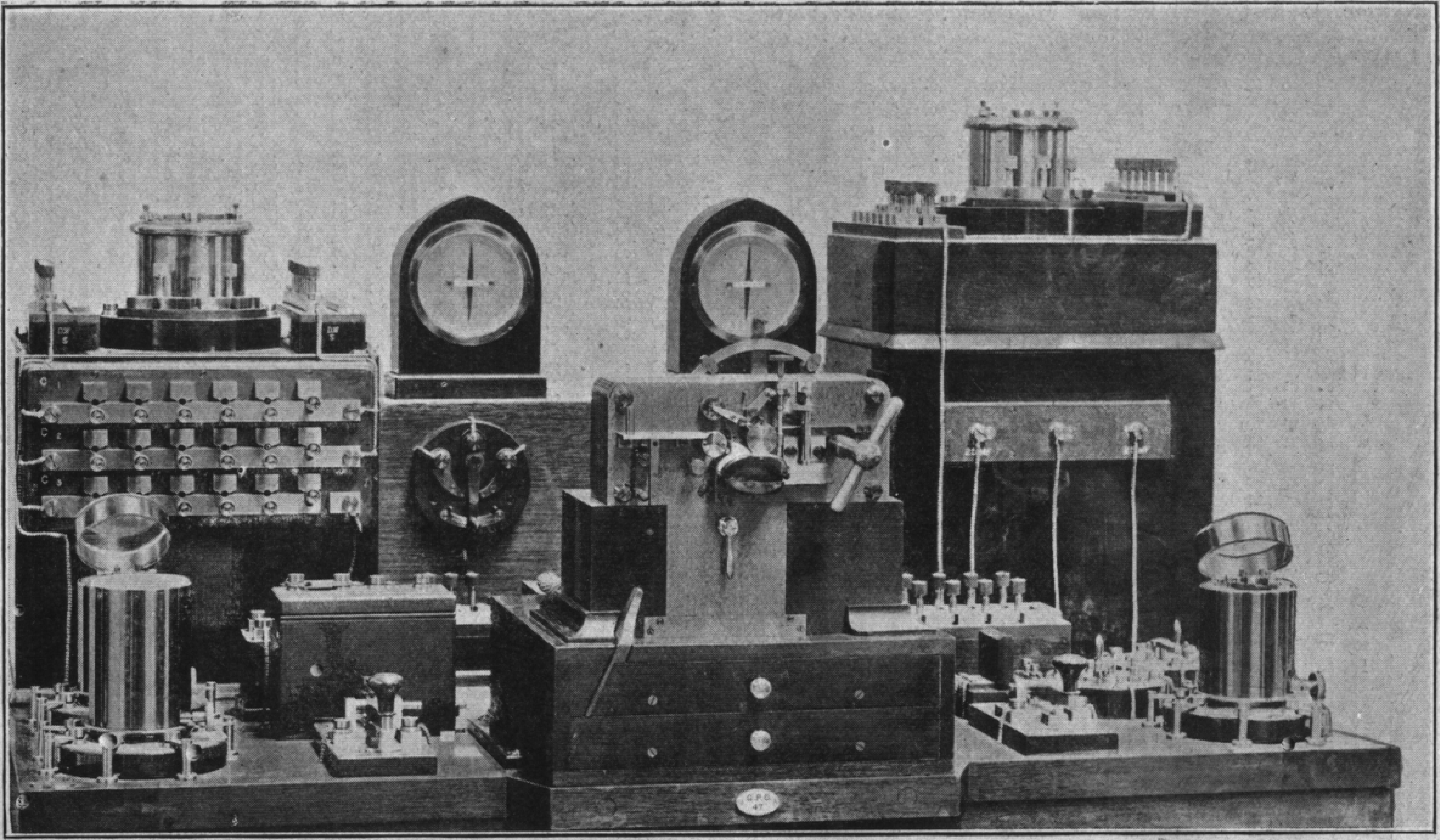


Fig. 171.—Hughes repeater: duplex or single.

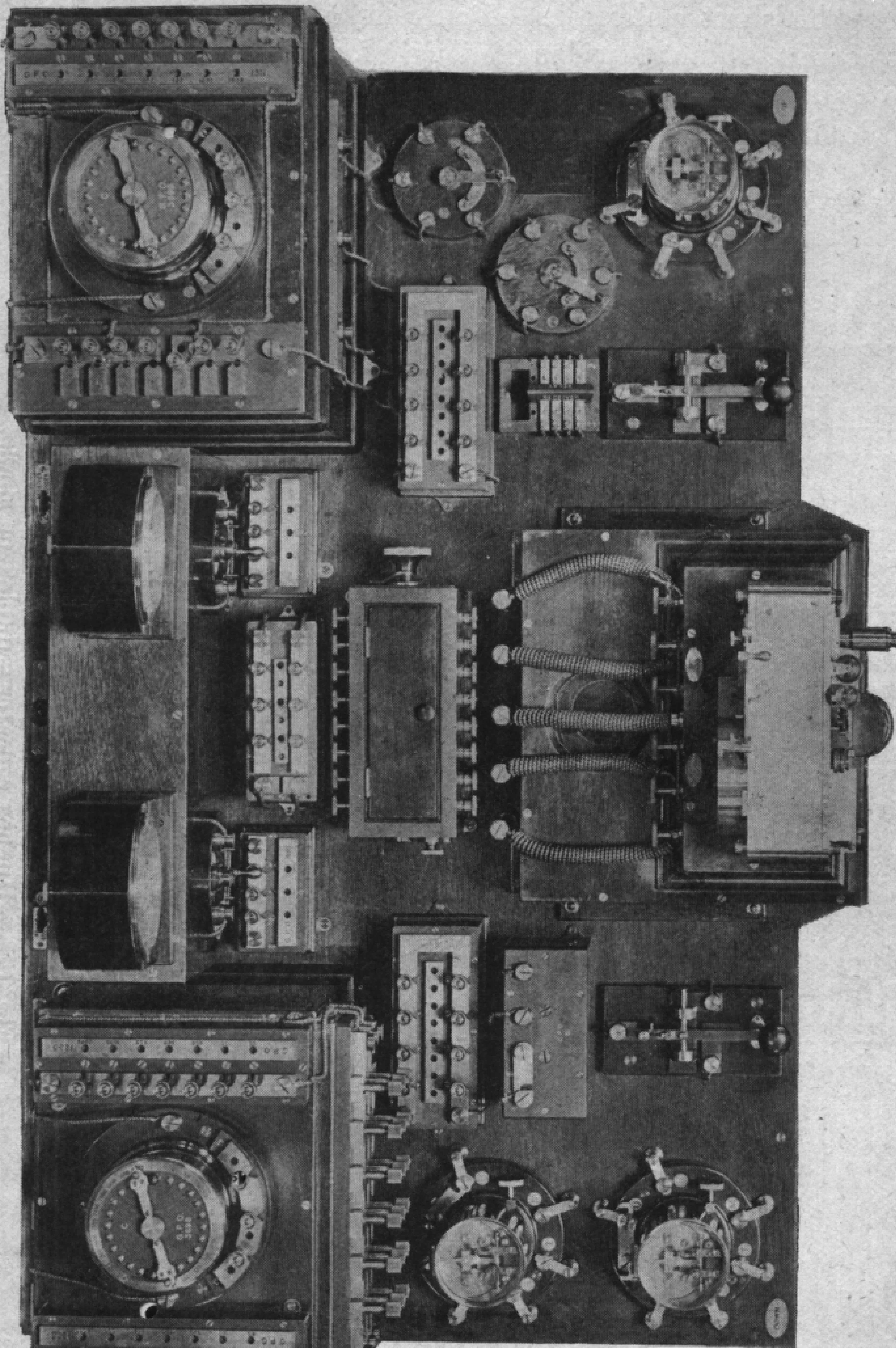


Fig. 172.—Hughes repeater: duplex or single—plan.

in opposite directions, they nullify each other—if the amounts be equal. The short pulsations of current, of which the Hughes signals consist, do not last long enough for the *resistance* of this leak to come into play as a shunt on the sent out current—as it would do if permanent currents were employed. The leak is

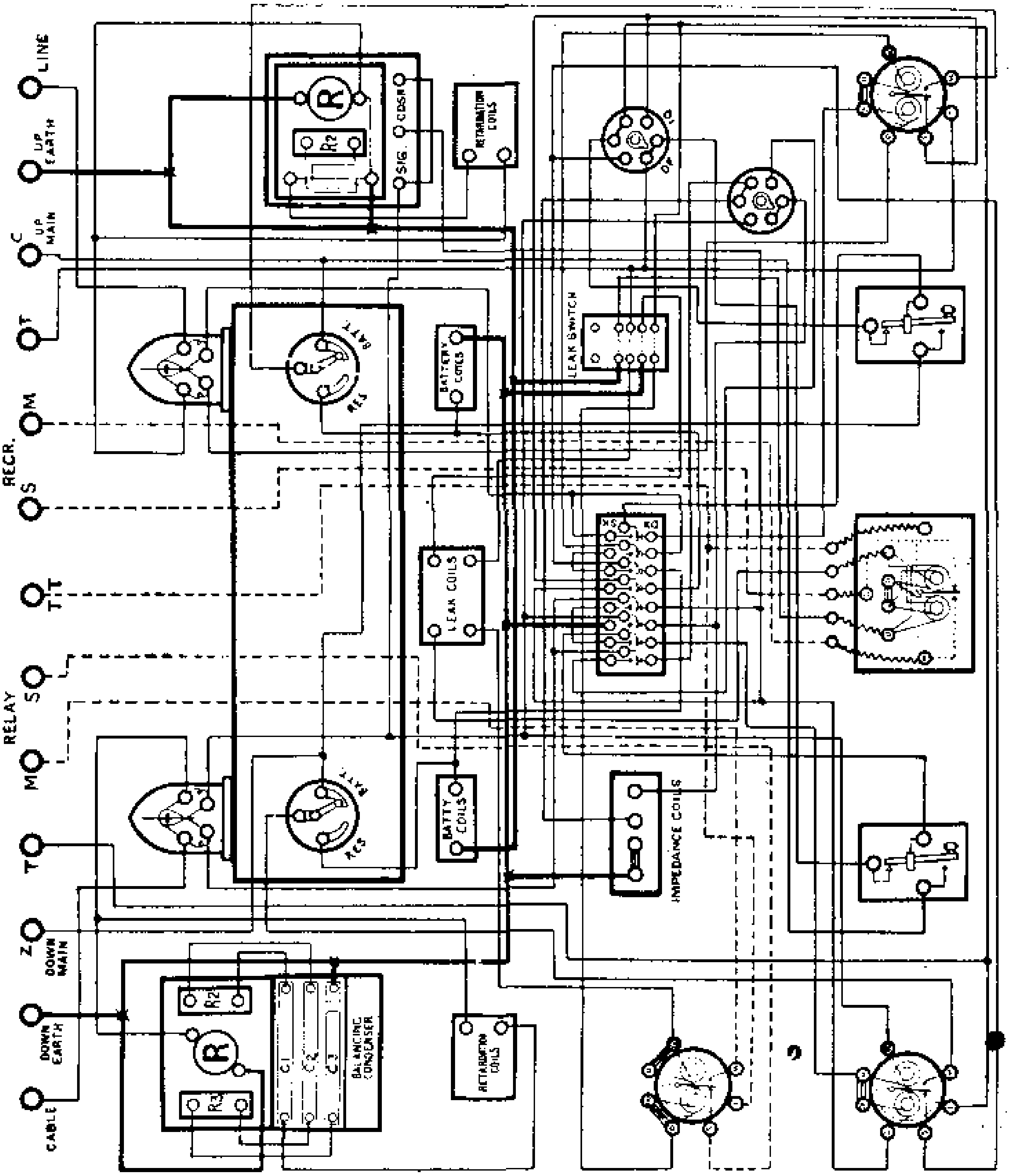


Fig. 173.—Hughes repeater: duplex or single.

placed on the inner side of the galvanometer, in order that the deflections of the latter may be due to the current actually passing to cable.

Another means of discharging consists in the employment of a relaying sounder, in place of the ordinary sounder, on the up side.* The lower contact of this instrument is connected to the spacing stop of the up transmitting relay and its lever to earth.

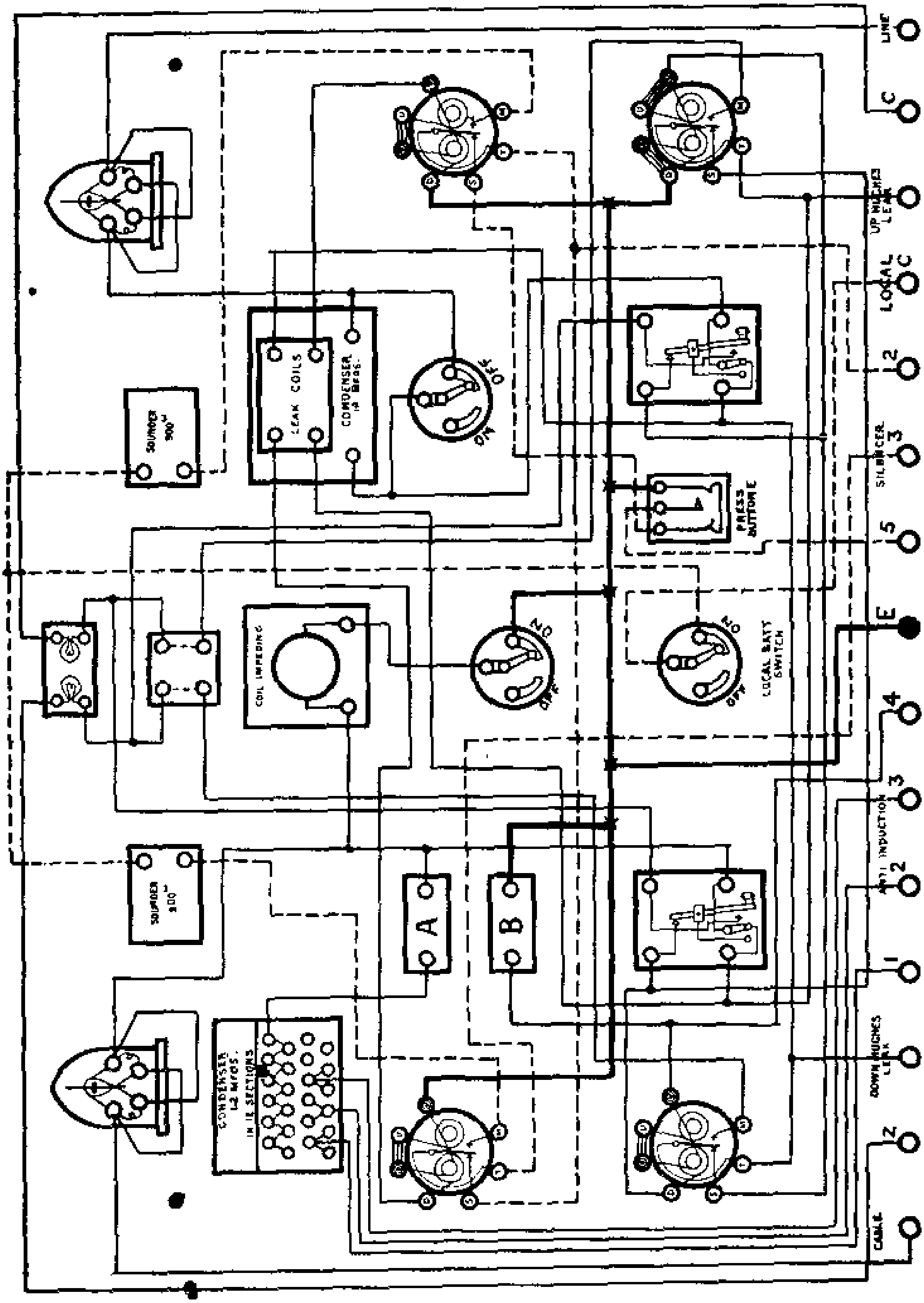


Fig. 174.

If, therefore, the relaying sounder lever be held down while the tongue of the up relay is at spacing, the cable is put direct to earth. The relaying sounder, as we have seen, is arranged to give considerable self-induction; hence, at the conclusion of every signal sent to cable, the relay tongue gets back to spacing before the armature of the sounder rises. The discharge from the cable, therefore, passes direct to earth.

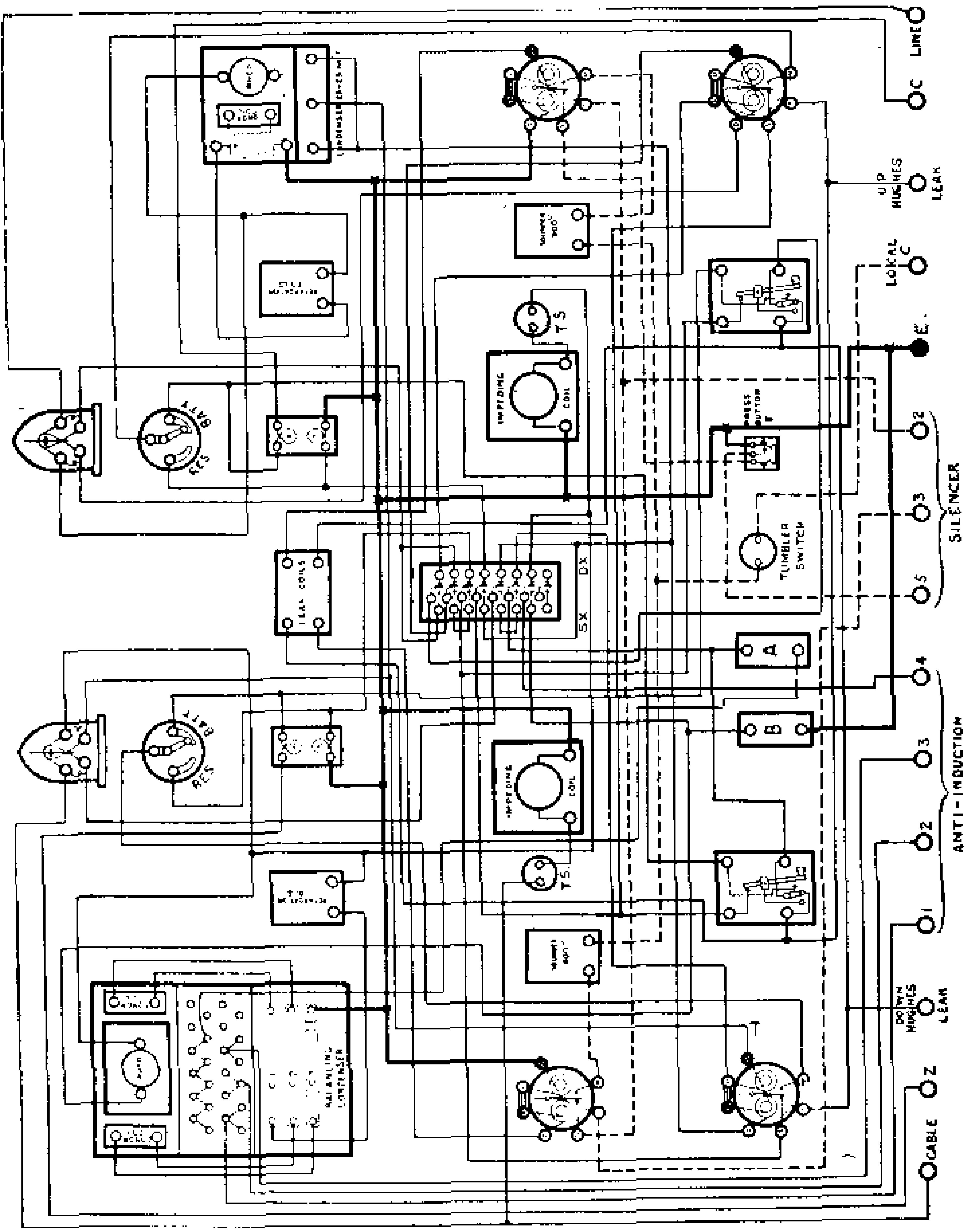


Fig. 175.

Hughes Duplex Repeater.—Fig. 171 gives a view of the complete board (excepting the sounders, which are mounted separately on suitable pillars), Fig. 172 a view from above, and Fig. 173 gives the full connections for a Hughes repeater, to be worked duplex or single at will, the necessary alterations being made by the eight-bar switch. It will be seen that, to balance the capacity of the cable, a triple condenser is employed, with three retarding coils. A Wheatstone receiver is in use on one of the leaks, instead of the ordinary relay, while to the right of the eight-bar switch is the "leak" switch. This furnishes a means of putting the receiver in the up and the relay in the down leak, or *vice versâ*. This practice is borrowed from the fast-speed arrangement to be described later, and is not strictly necessary. Indeed, the receivers are being replaced by relays. Each main battery, as can be seen, is provided with a separate two-way switch, and a second six-terminal one is provided for the electro-magnetic leak.

Duplex working is employed between London and Amsterdam and Rotterdam, with duplex repeaters at Lowestoft, and, amongst others, between London and Magdeburg, Hamburg, &c., with duplex repeaters at Lowestoft or North Walsham and Emden.

Latest arrangements. The electro-magnetic leak coils shown in the preceding diagrams have now been replaced by another type. Anti-induction devices are also employed, to prevent the signals sent on one conductor of a cable giving rise to inductive currents on the other conductors. This is effected by an arrangement of small condensers so placed that, for every signal sent on its own wire, an impulse is sent on all the other wires in the reverse direction to the inductive currents. These and several other re-arrangements are included in the new boards shown in Figs. 174 and 175, which also imply the use of secondary batteries. The former illustrates a single, and the latter a duplex or single, board.

FAST SPEED REPEATERS.

From the preceding consideration of double current and duplex working, the principles of fast speed repeaters will be easily understood. Such a repeater, duplex or single, of standard pattern, is shown in Fig. 176. Instead of having the major portion of the apparatus mounted on a single board, and the sounders and a few other instruments placed on shelves near by, as in the old arrangement, a second tier or smaller board is added to the lower board, and the whole set is then self-contained and complete. The set actually shown is one for working from

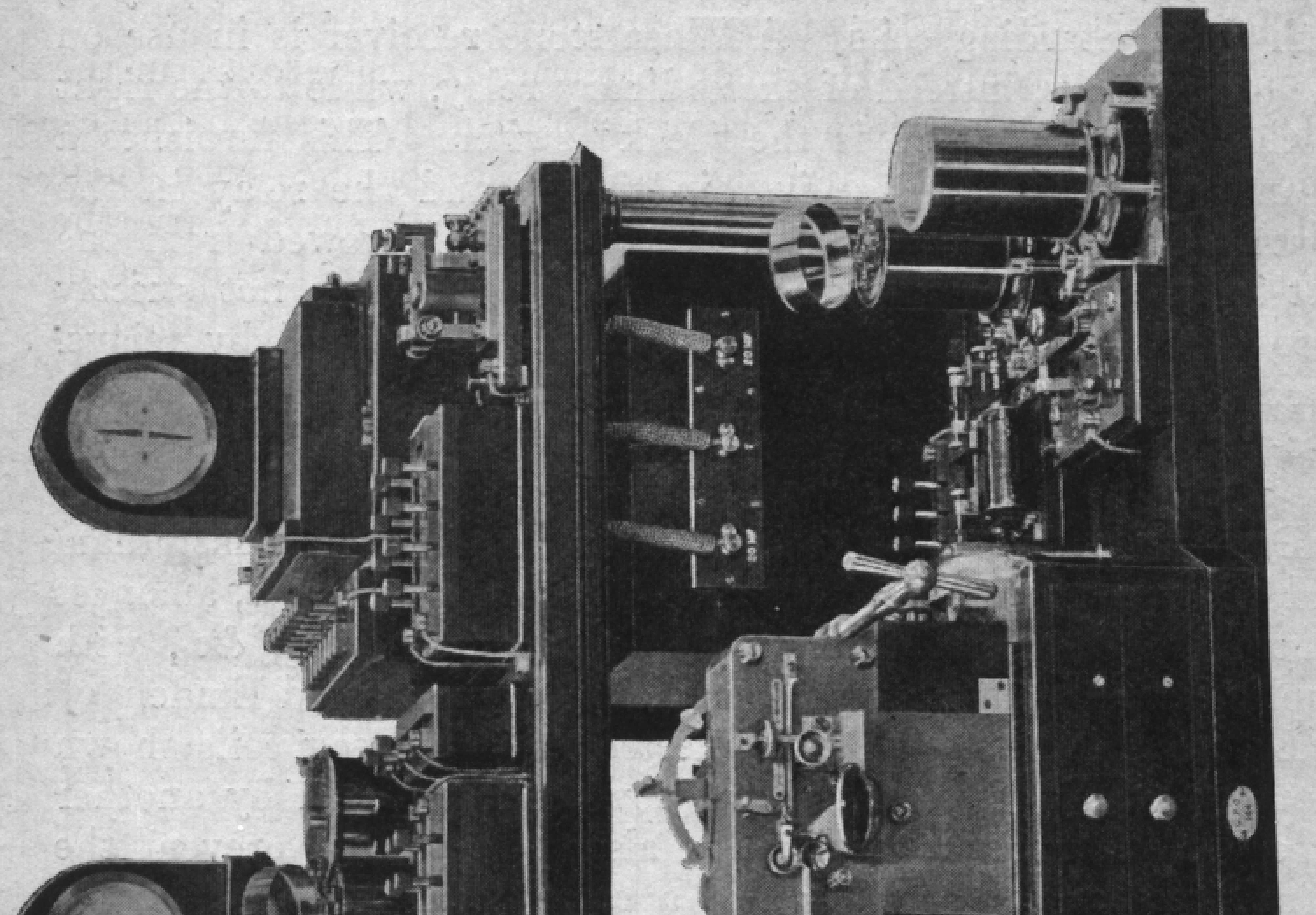


Fig. 176.—Fast speed repeater : duplex or single.

a land line to a submarine cable, the latter being on the down side. A triple condenser for the cable compensation circuit is seen on that side of the lower board. It is worked differential on the land and bridge on the cable side. The full diagram is given in Fig. 178, and a skeleton diagram in Fig. 177 by which the arrangements can be easily seen.

The two six-terminal switches, labelled "resistance—battery," in one position connect the main batteries to the relays; in the other position, the battery coils are substituted for the batteries. These are to enable the terminal stations to balance with their galvanometer needles vertical. The keys employed are the "single-current, with switch" form. The D F and I Q switch of the Hughes repeater is unnecessary, with these keys in use,

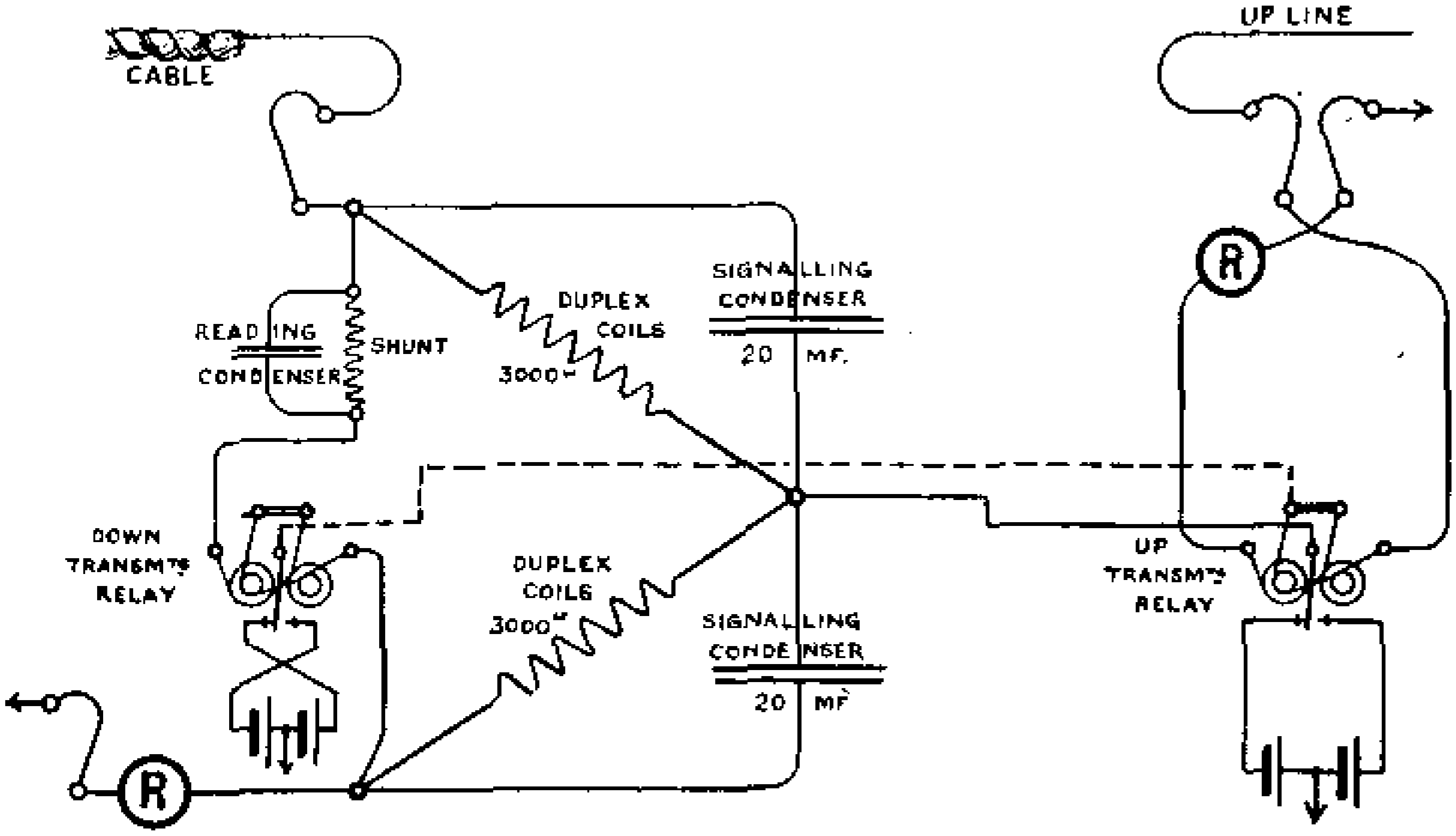


Fig. 177.—Skeleton of Fig. 178.

because, by the act of turning the switch on the key, the relay tongue is cut off from the line. The repeater operator may desire to check the Wheatstone signals on one side or the other. The leak switch, on the right of the down key, enables the receiver to be thrown into either leak circuit at will. In simplex working, one leak only being then in use, the receiver or the relay may be used by placing the plug with the side engraved "receiver" or "relay" upwards in the upper slot of the switch.

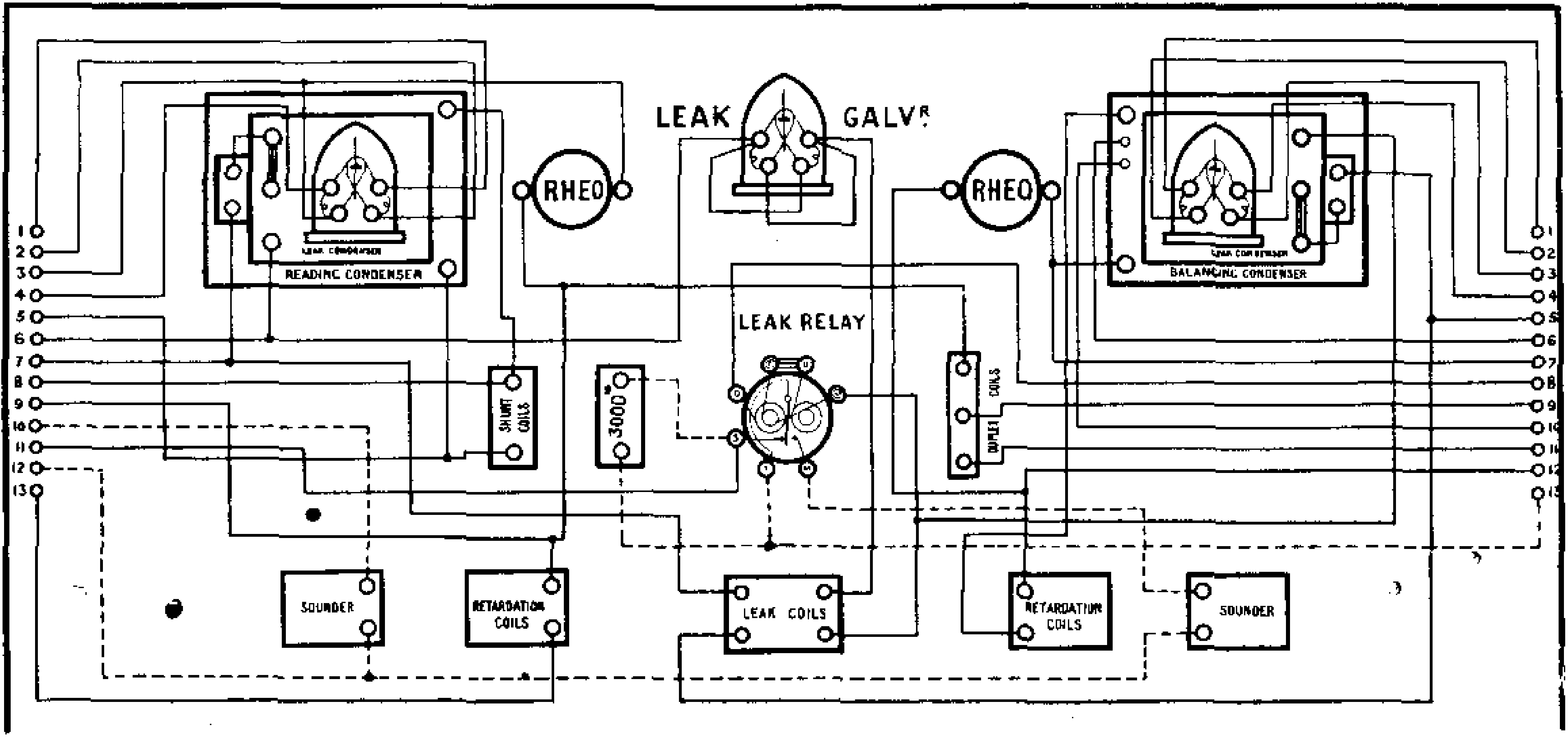
Forked News Repeater.—Where large quantities of press work are to be distributed to many centres, the common arrangement is a Y Q circuit, including as many of the required towns as possible. This Y Q circuit is frequently a "forked" one, and

FAST SPEED REPEATER.

Duplex and Single—Cable on Down Side.

Bridge to Cable—Differential to Land Side.

UPPER BOARD.



LOWER BOARD.

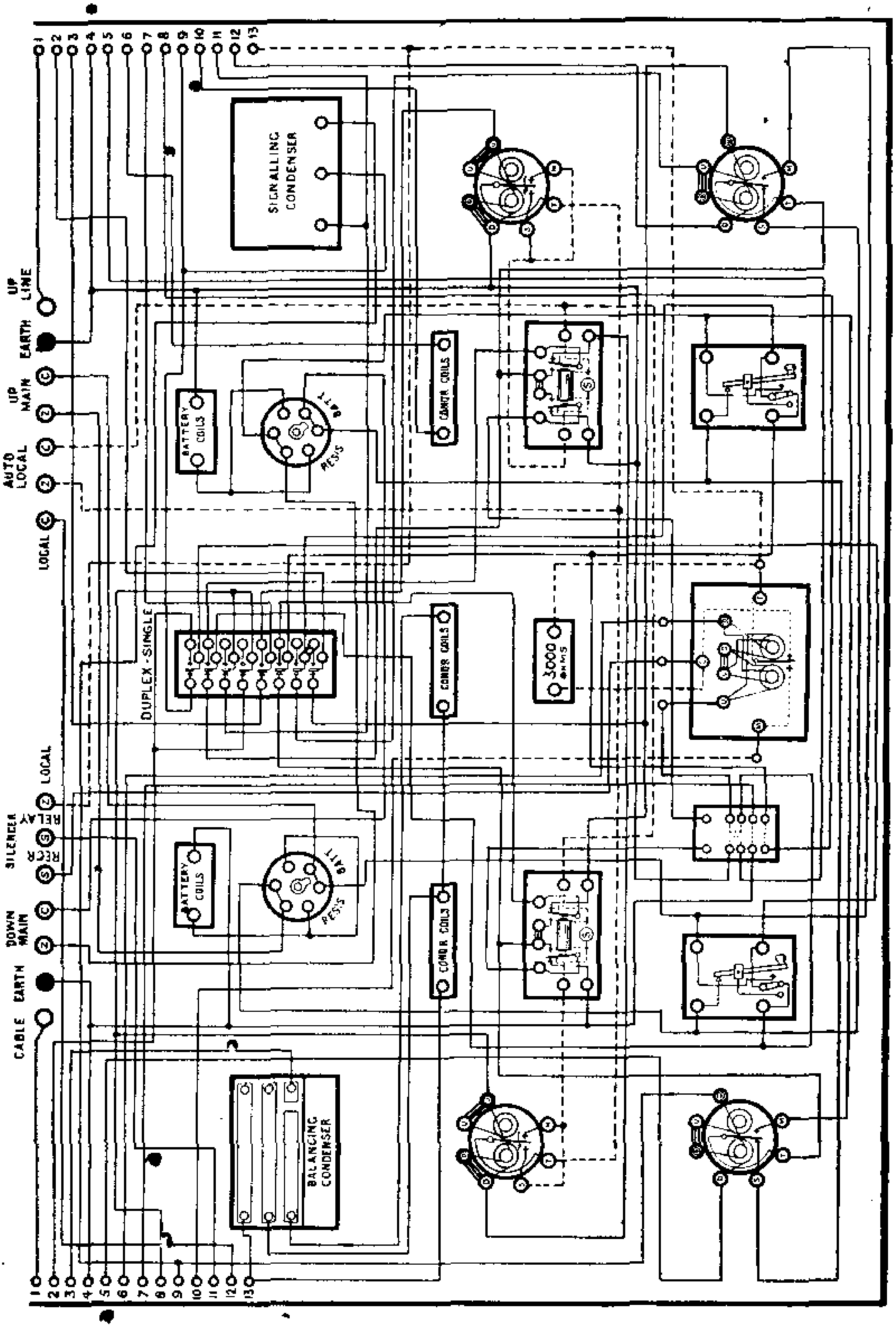


Fig. 178.

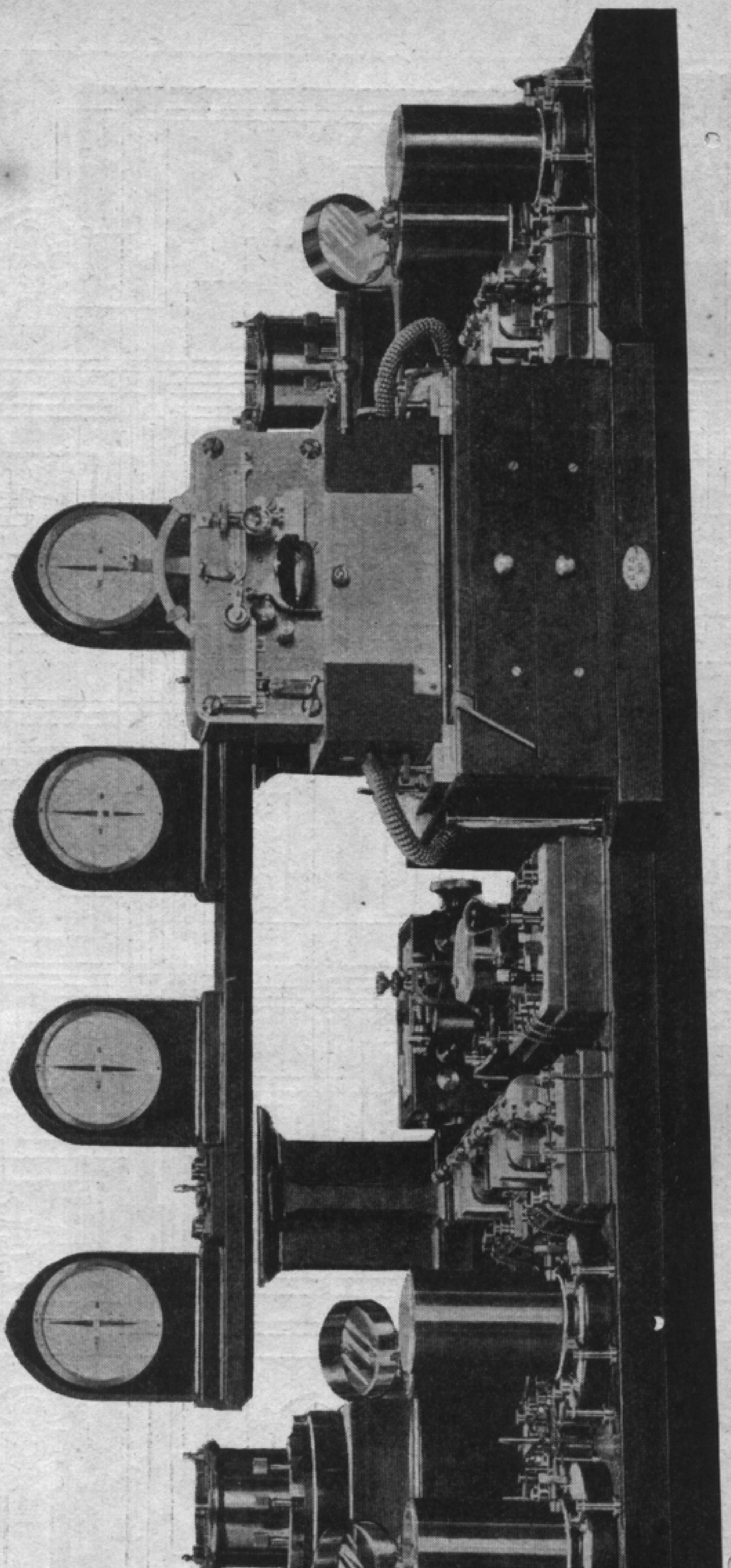


Fig. 179.—Forked news repeater.

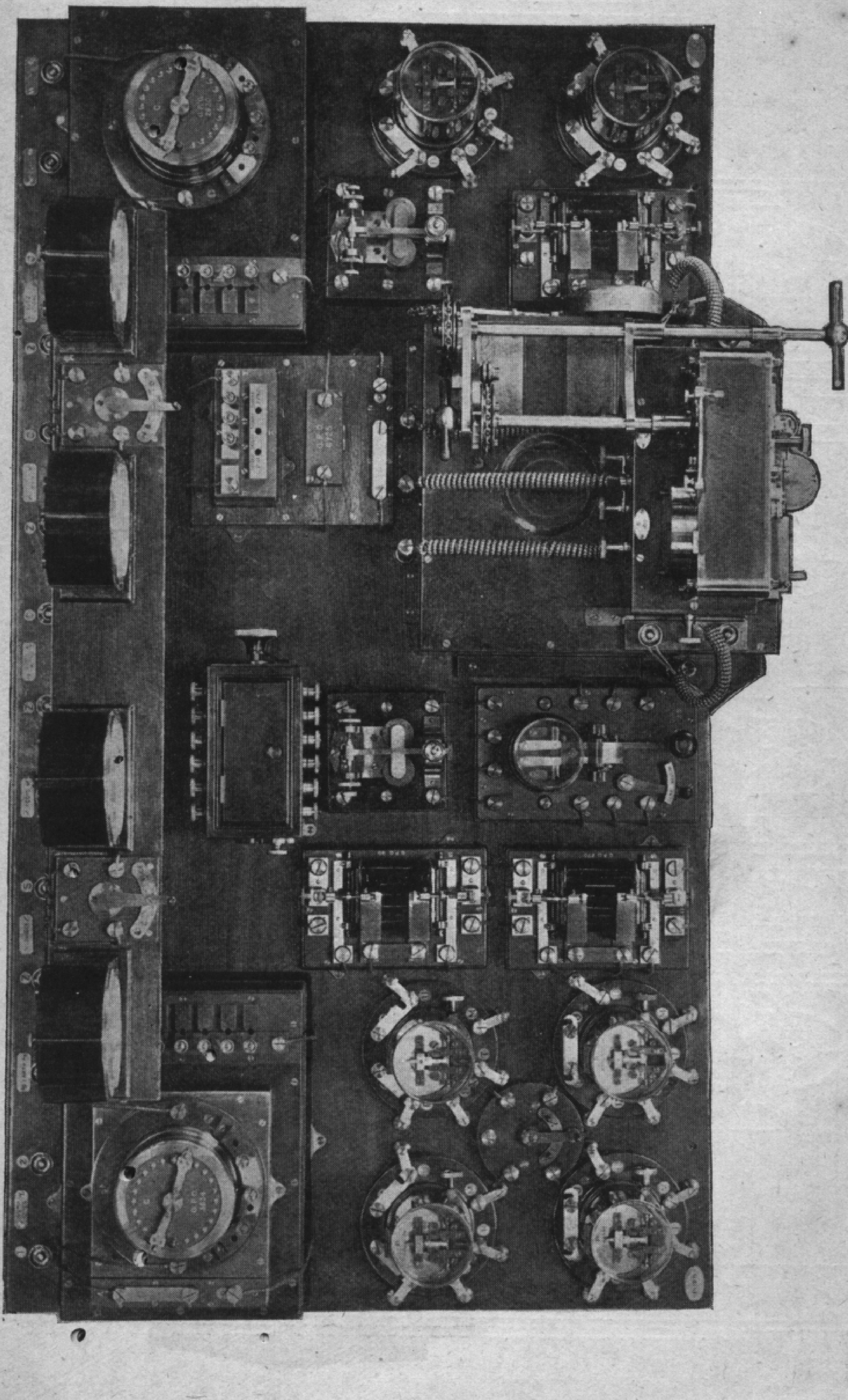


Fig. 180.—Forked news repeater: plan.

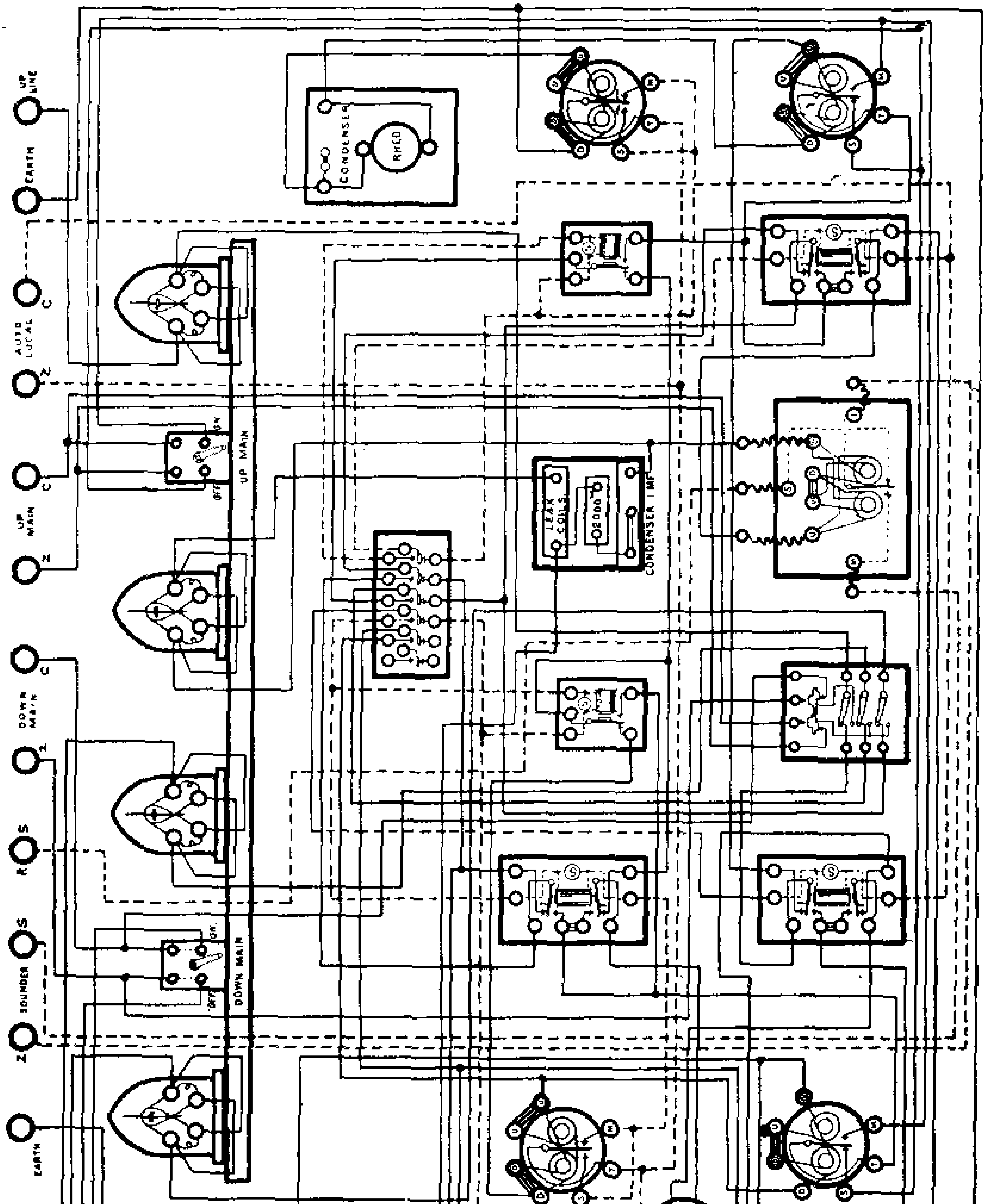


Fig. 181.—Forked news repeater.

a repeater is conveniently placed at the fork. The transmitting office then sends along the single line to the repeater, which automatically works the two branches of the fork. Such a repeater is shown in Figs. 179 and 180, the diagram of connections in Fig. 181, and a skeleton of the latter in Fig. 182. Little comment is required, as the diagrams are almost self-explanatory. The six-terminal two-way switch on the left is to enable the leak circuit to be worked from either of the two down relays, irrespective of which down station is sending.

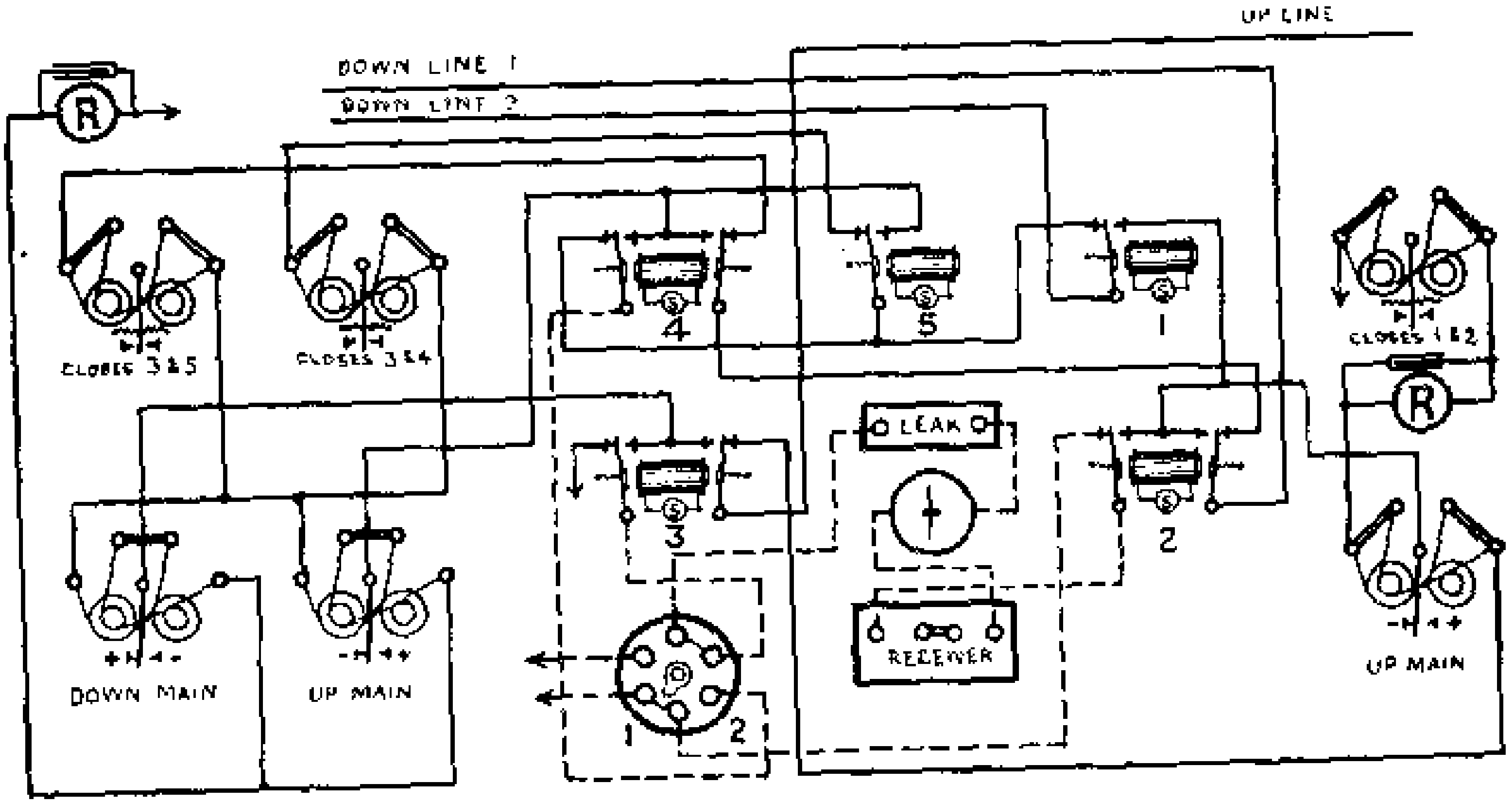


Fig 182.—Forked news repeater: skeleton of connections.

QUADRUPLEX REPEATERS.

In our consideration of quadruplex we saw that the great difficulty, the splitting of the B side signals, was inherent in diplex working. Similarly here, the crux of the trouble is in repeating diplex; hence we will consider this first.

Pole-changer or Pole-reverser.—This and the incrementer have always been associated with attempts at quadruplex repeating. The former, shown in Fig. 183, is a simple sounder with its armature lever extended backwards so as to play between a pair of flexible contacts mounted in a circular brass box seen in the front of the figure. The moving end of the lever, the contacts, and a fixed stop form the equivalent of a double-current key, arranged to short-circuit the battery in its movement from one position to the other.

Incrementer or "single-current transmitter."—Like the pole-reverser, this instrument (Fig. 184) is a sounder, with the armature lever prolonged at the back. At this end it (L) is hook-shaped, and under the hook is a platinum contact. Engaging with this is a light flat spring, T, similarly provided with a contact, and insulated from the rest of the instrument. Just

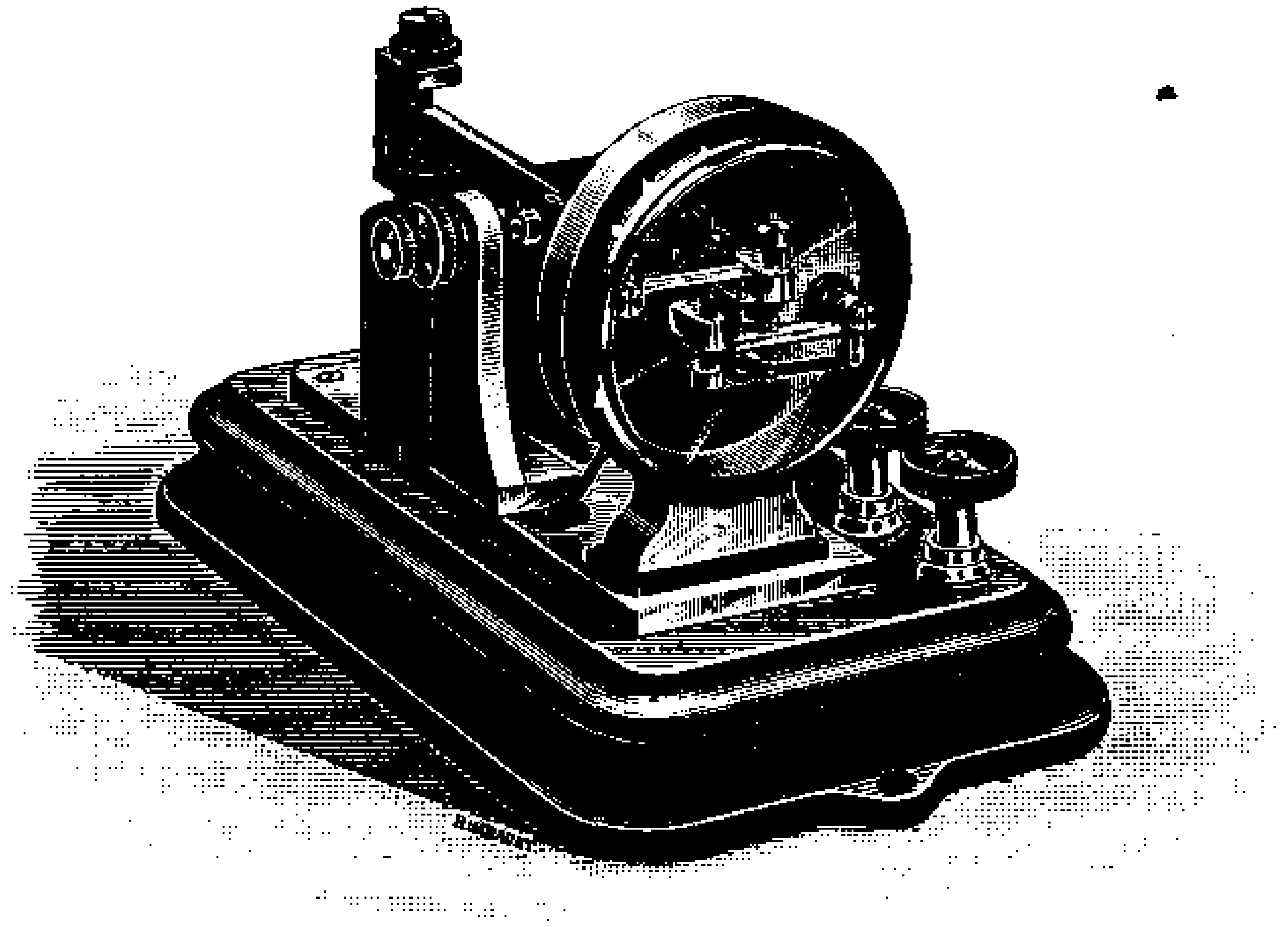


Fig. 183.—Pole-reverser.

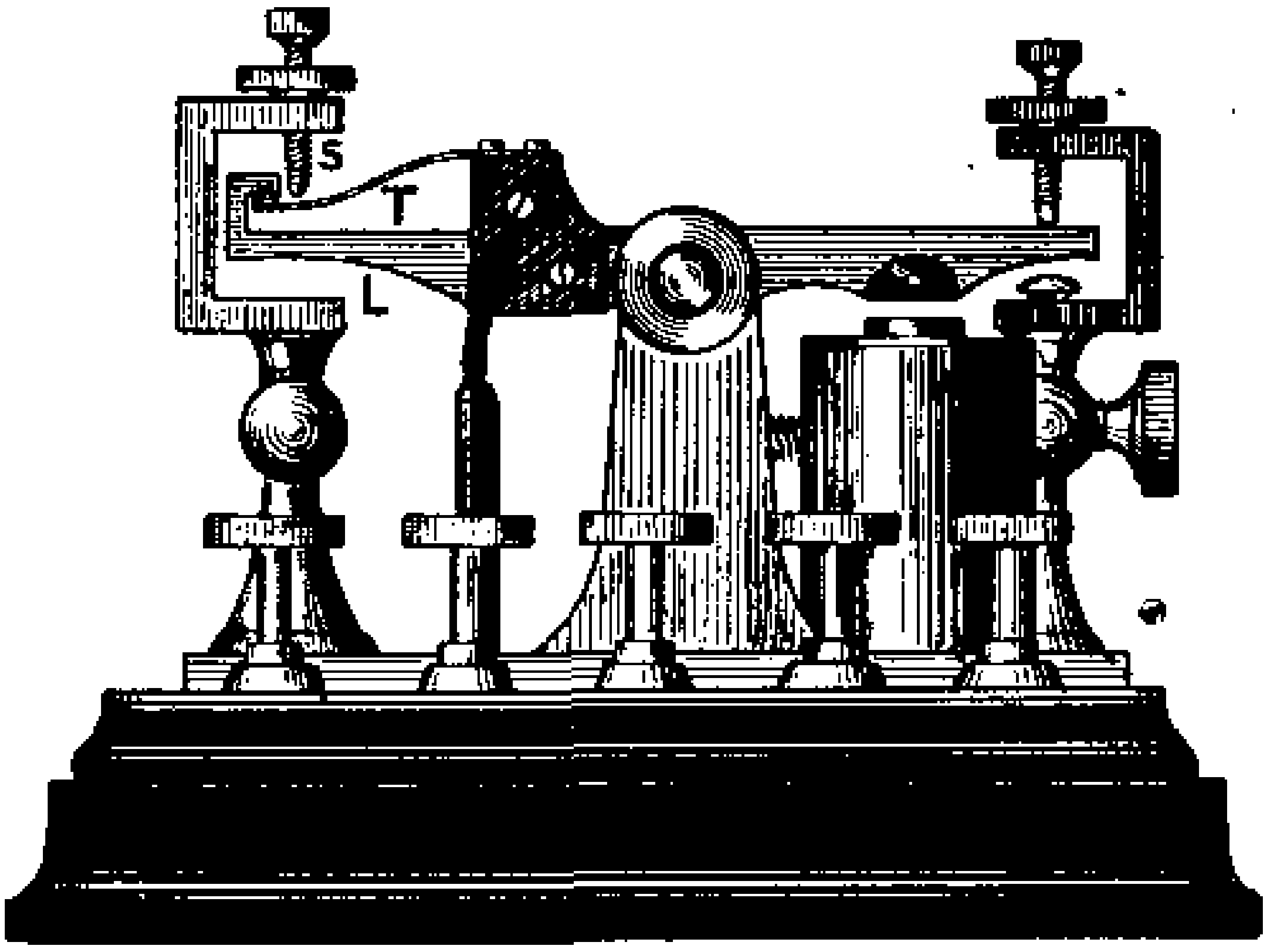


Fig. 184.—Incrementer.

above the spring is a contact screw, S, supported by a brass standard. When the instrument is at rest the spring makes contact with the hooked end of the lever, but when the armature

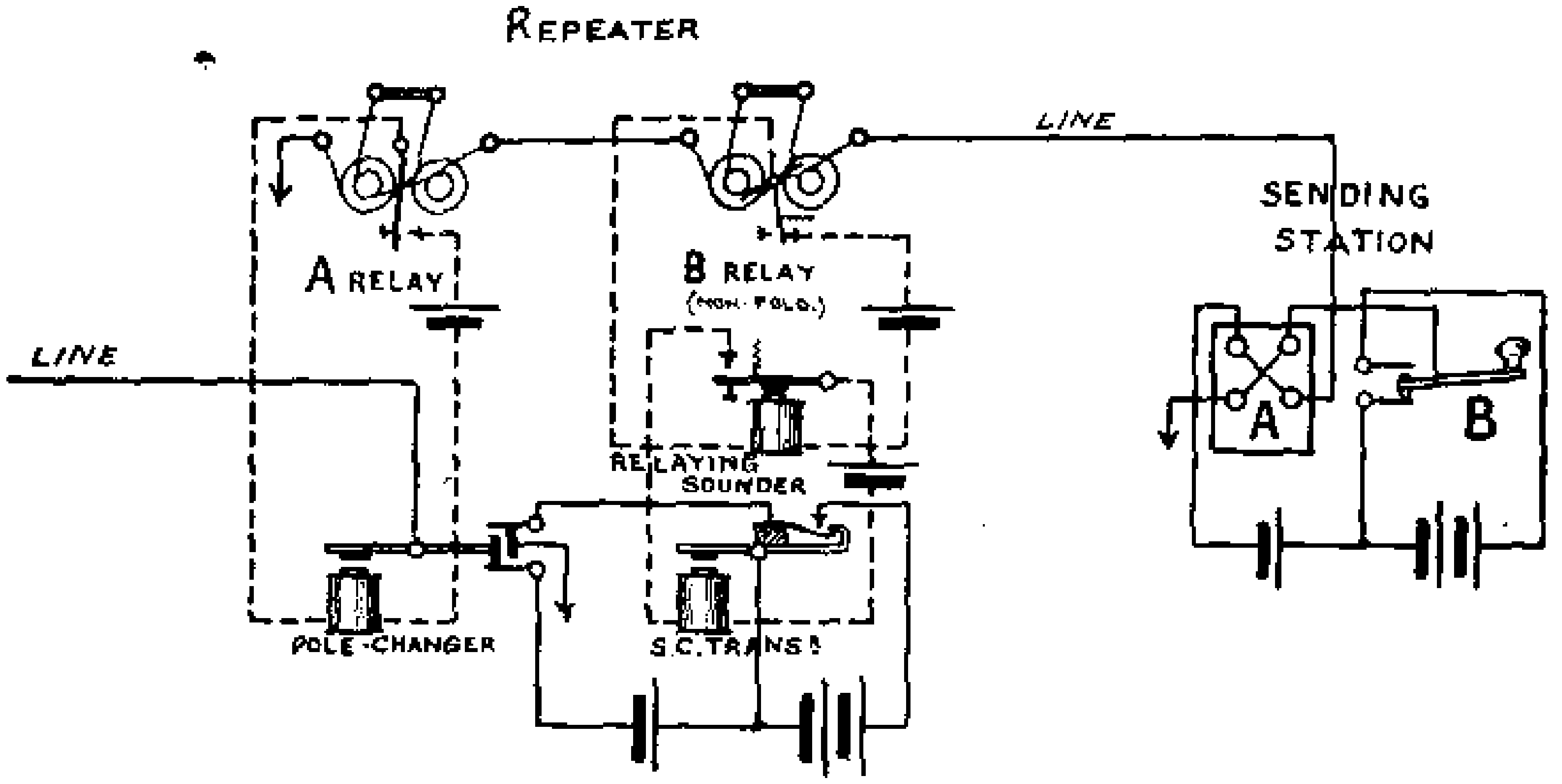


Fig 185.—To repeat diplex—old plan.

is attracted the hook moves upwards, causing the spring to butt against the upper contact screw and to break its connection with the lever. As the one contact is made before the other is broken, short-circuiting takes place as in the pole-reverser.

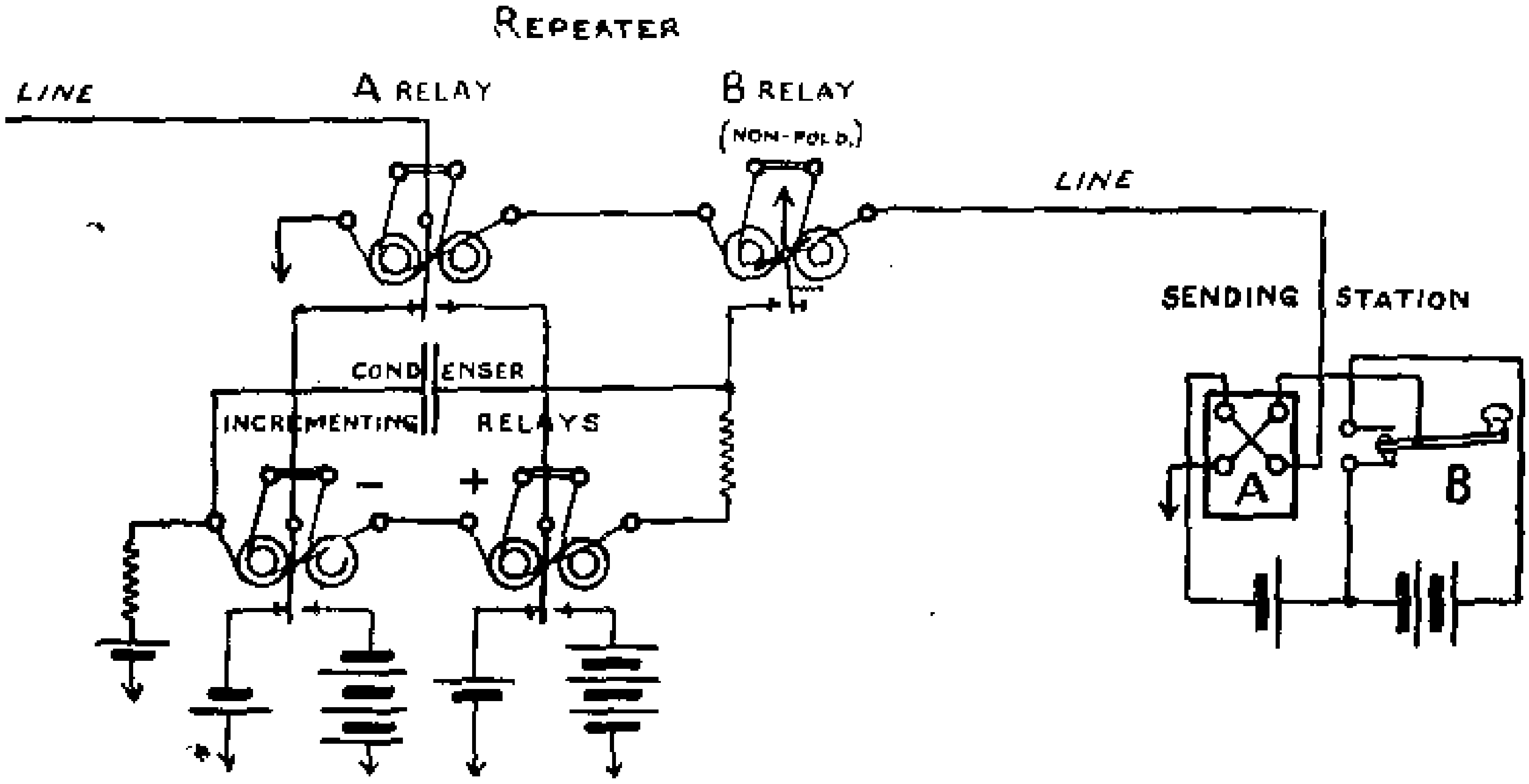


Fig. 186.—To repeat diplex—present plan.

Diplex Repeater.—Fig. 185 gives the theoretical arrangement of the apparatus necessary to repeat diplex on the old plan. The depression of the A key at the sending station works the

A relay, the completion of whose local circuit actuates the pole-changer, and thus reverses the direction of the sent-out current. When the B key is depressed the B relay is actuated and its local circuit broken. The armature of the relaying sounder is released and the circuit of the incrementer closed. The latter thus brings in the full battery and augments the sent-out current.

Fig. 186 gives the present-day arrangements. The pole-changer, incrementer, and relaying sounder are discarded, and only standard relays used. The A relay tongue now gets its connection with the batteries by means of the tongues of two additional or "incrementing" relays. With the apparatus at rest, as shown in the diagram, the negative pole of the small battery is connected to the line. If the sending-station's A key be put down the A relay tongue moves over to marking, and the positive pole of a battery of similar strength is connected to line. If the B key be depressed the B relay is actuated and its local circuit closed (as in the present quadruplex system). Its tongue, being to earth, thus completes the circuit of the battery on the left, and the tongues of the incrementing relays move over to marking. Whatever the position of the A relay tongue the current is thus augmented to the B value. A condenser is placed across the two relays, so that if any splitting should occur at the B relay (which would cut off the current from the incrementers) the condenser discharge will keep the tongues of the two relays on the proper stop, and thus prevent the reproduction of the split in the repeated signal.

Quadruplex Repeater.—The full diagram is given in Fig. 187. With the exception of the additional receiver, sounder, and combined 12-bar switch, the apparatus grouped on the left of the figure simply constitutes an ordinary fast-speed repeater, the whole of the additional apparatus required for the B repeating being grouped on the right. The electrical arrangement is better seen in the skeleton diagram (Fig. 188). To assist in tracing connections the relays are all numbered in both Figs. 187 and 188. It will be seen that, while the two receivers are in the usual positions in the leak circuits, the corresponding B relays, instead of being placed in the leaks, are actually in the compensation circuits (of the opposite sides). This arrangement gives a better indication of the probable state of the signals at the distant station, as the relay thus occupies a position in the compensation circuit similar to that occupied in the line by the

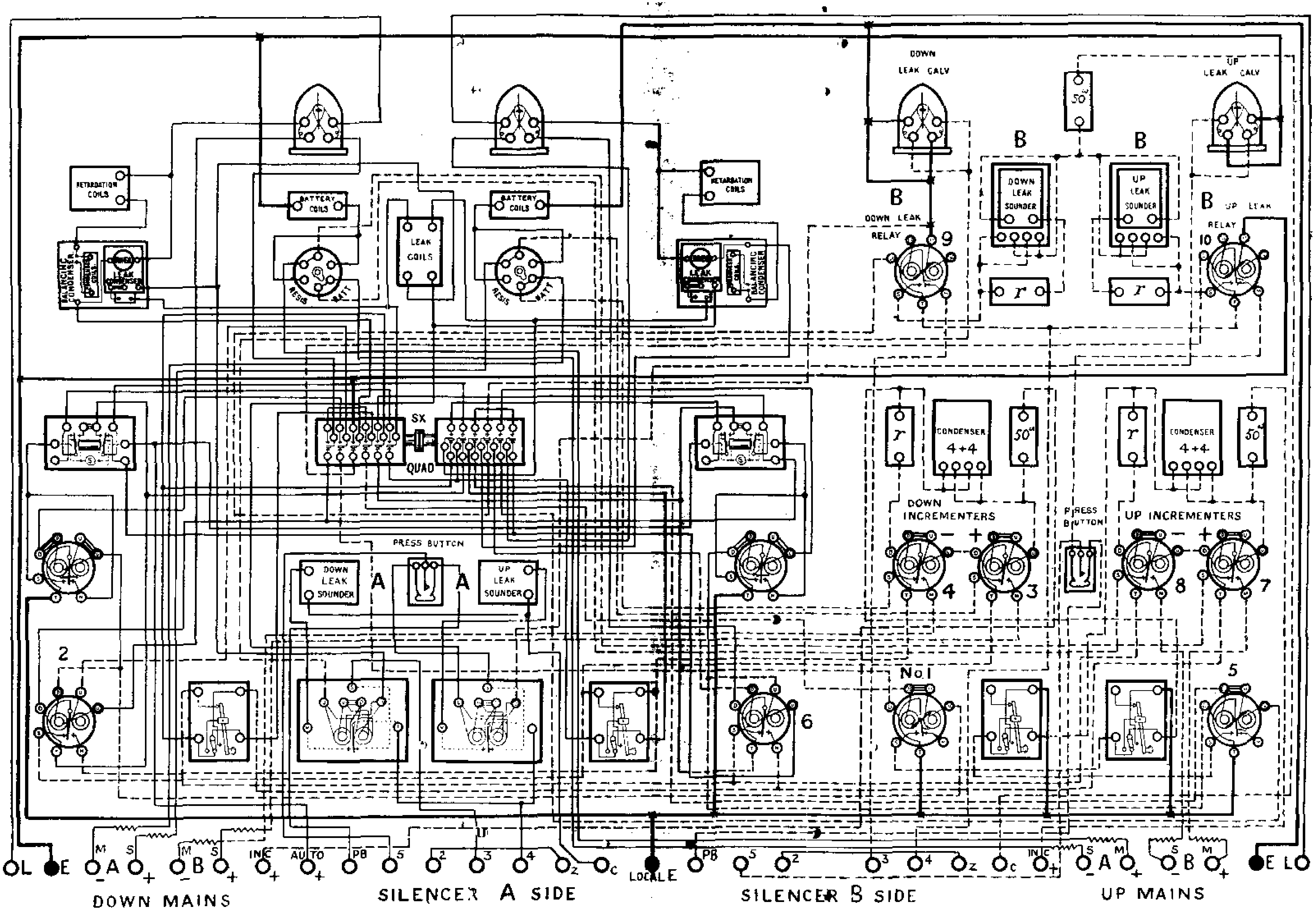


Fig. 187.—Repeater: quadruplex or single.

receiving relay. To render them still further alike, only one coil of the B relay is in use. The leak *signals, both A and B, however*, are shown on the respective leak galvanometers.

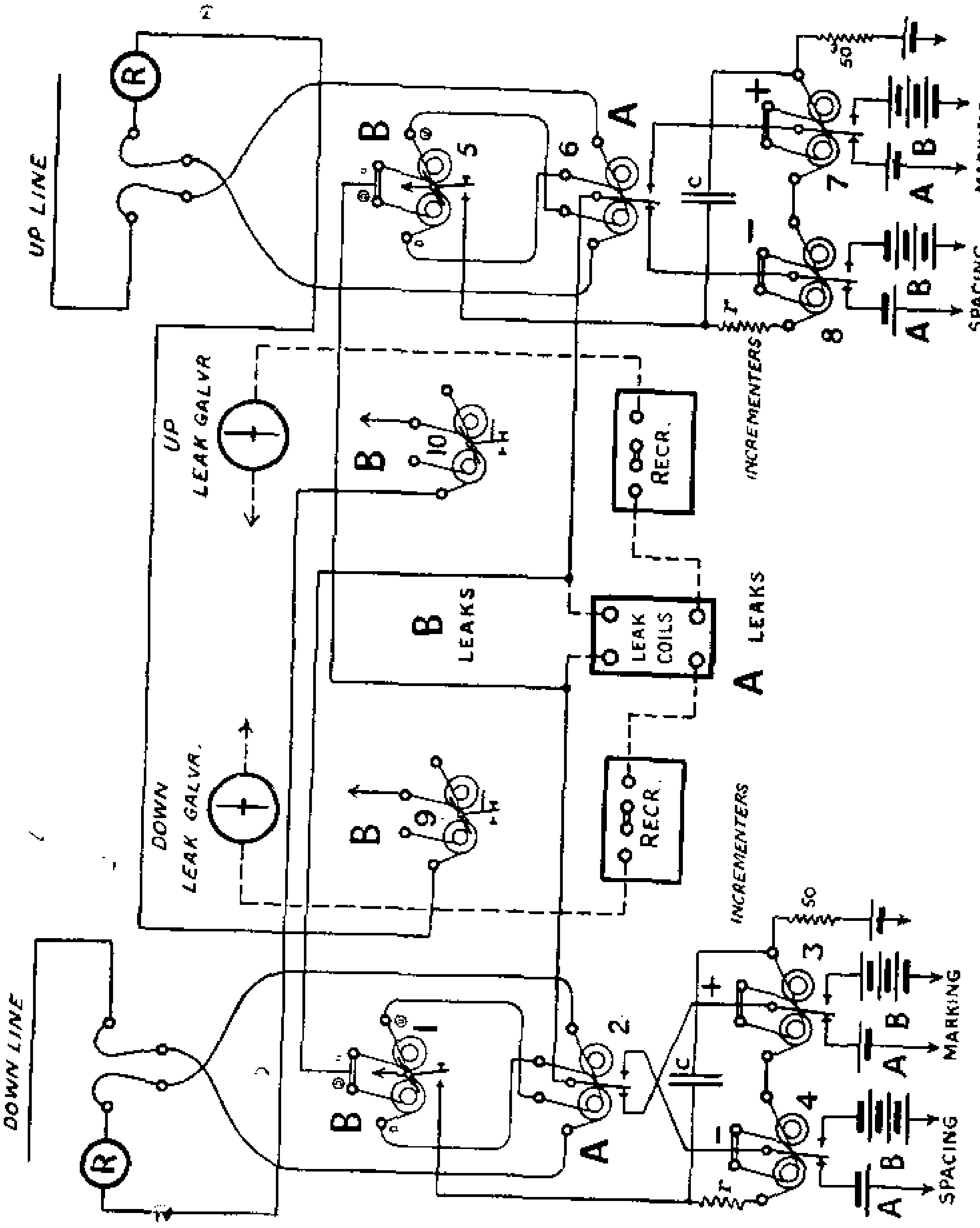


Fig. 188.—Quadruplex repeater: skeleton.

Forked Quadruplex Repeater.—*Several varieties of quadruplex* or quadruplex repeater are now arranged. The first, a forked quadruplex repeater, is shown in skeleton in Fig. 189. The up office works full quad. At the repeater station

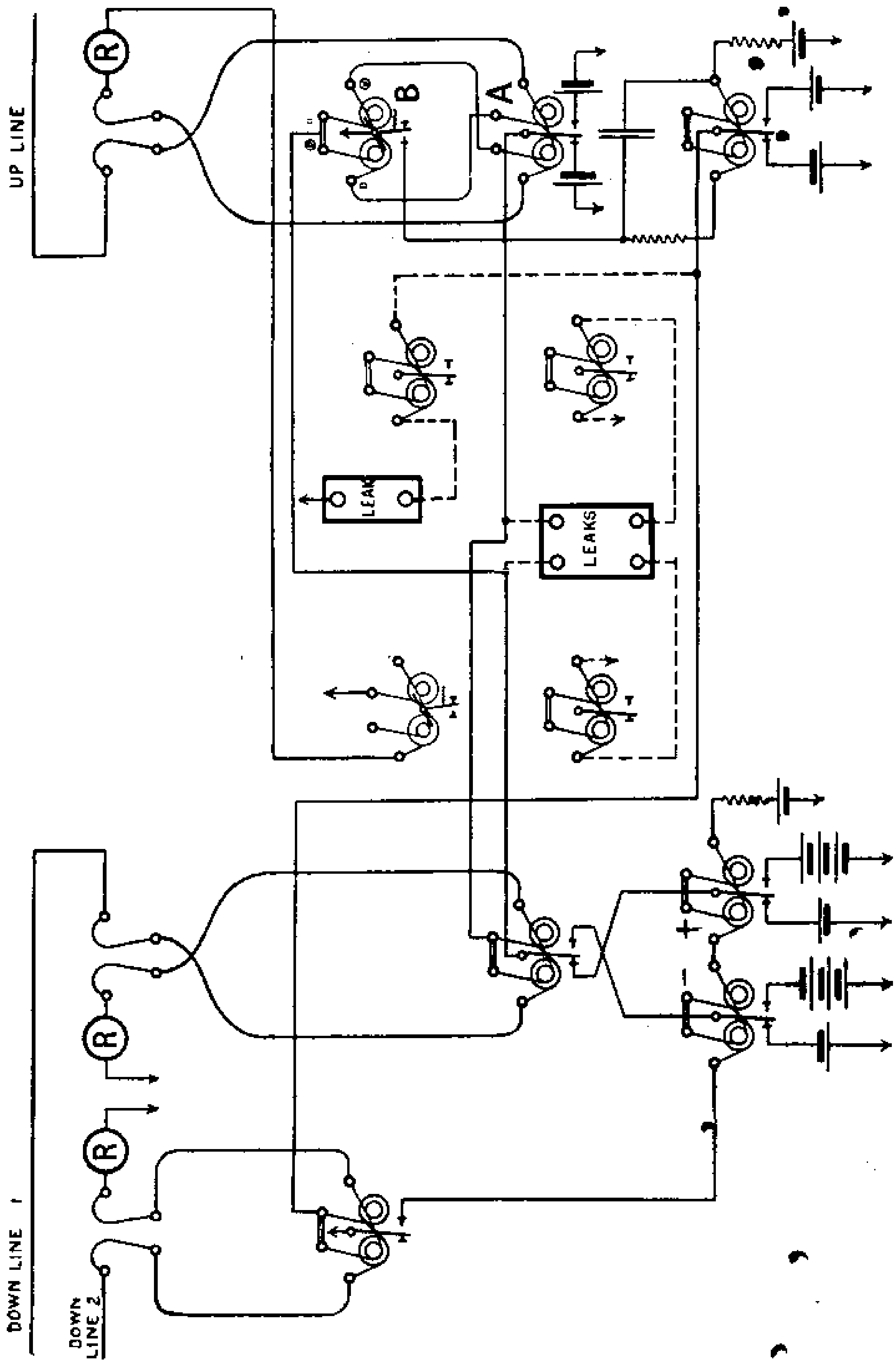


Fig. 189.—Forked quadruplex repeater.

of both A and B sides working to another single line, each works a separate line. Thus the two down stations work to the up, one on the A and the other on the B side—both the down offices being simply furnished with duplex apparatus.

When the up station depresses his A key the A relay on the up side of the repeater is actuated, and its tongue sends by the split of one of the down relays to down line No. 1 and its compensation circuit. The A leak is also worked. When the up station depresses his B key the B relay tongue sends a current through the coils of a third relay on the up side of the repeater. The tongue of this relay sends by the split of the other down relay to down line No. 2 and its compensation circuit. This third relay has a condenser across its coils to prevent the repeating of any break at the B relay. The leak in this case is a simple polarized relay like the other.

When down station No. 1 sends (No. 2 being at rest) its relay on the down side of the repeater is actuated, and its tongue, by means of the weak batteries on the incrementing relays (which are to spacing), sends to the split of the up side relays. Its leak is also actuated in the usual way. When down station No. 2 sends, the other relay on the down side responds, and its tongue actuates the incrementing relays and brings the larger batteries to the contacts of the other relay on the down side, thus augmenting the current to the split of the up relays. The B relay, which serves as the "leak" in this case, is in the up artificial circuit.

Split Quadruplex Repeater.—This, shown in skeleton in Fig. 190, is an arrangement whereby two terminal stations, X and Y, furnished with quadruplex apparatus, work to each other on the A side through a duplex repeater at station Q. Both X and Y also work to Q direct on their respective B sides. Station Q is thus half a repeater and half a working office on the circuit. The plan is really a doubling of the "quadruplex, A side relayed" arrangement. Fig. 190, of course, shows only the station Q. On the extreme right are the sending key and receiving apparatus (all shown in heavier lines) by which Q works direct to, say, station Y, and, on the left, similar apparatus, by which Q works to X. Thus, the depression of the B keys at the outer offices simply actuate the B relays at the intermediate office. The movement of the A key at either of the distant offices actuates the A relay at the repeater, whose tongue sends on a fresh signal to the other station.

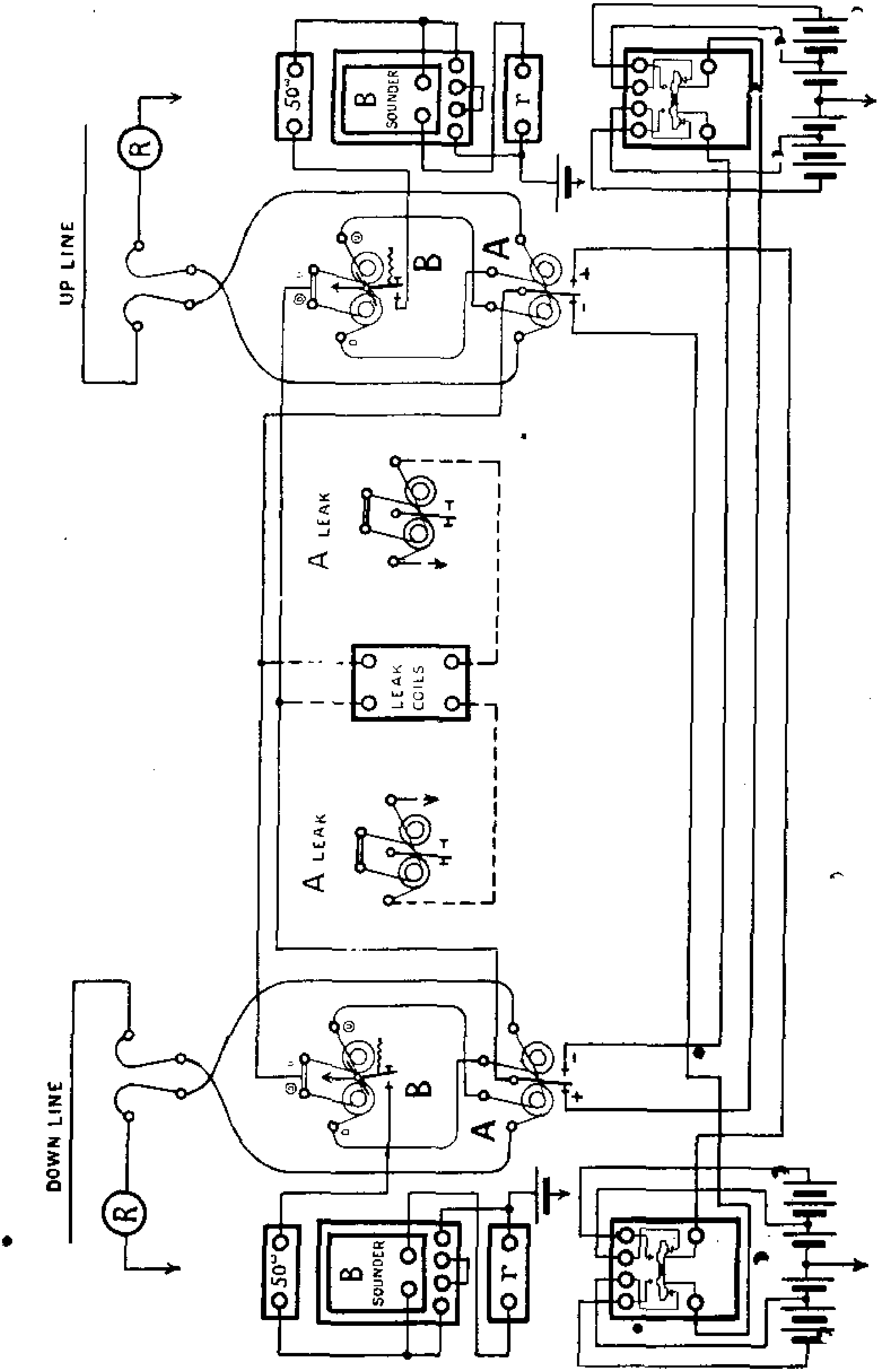


Fig. 190.—Split quadruplex repeater.

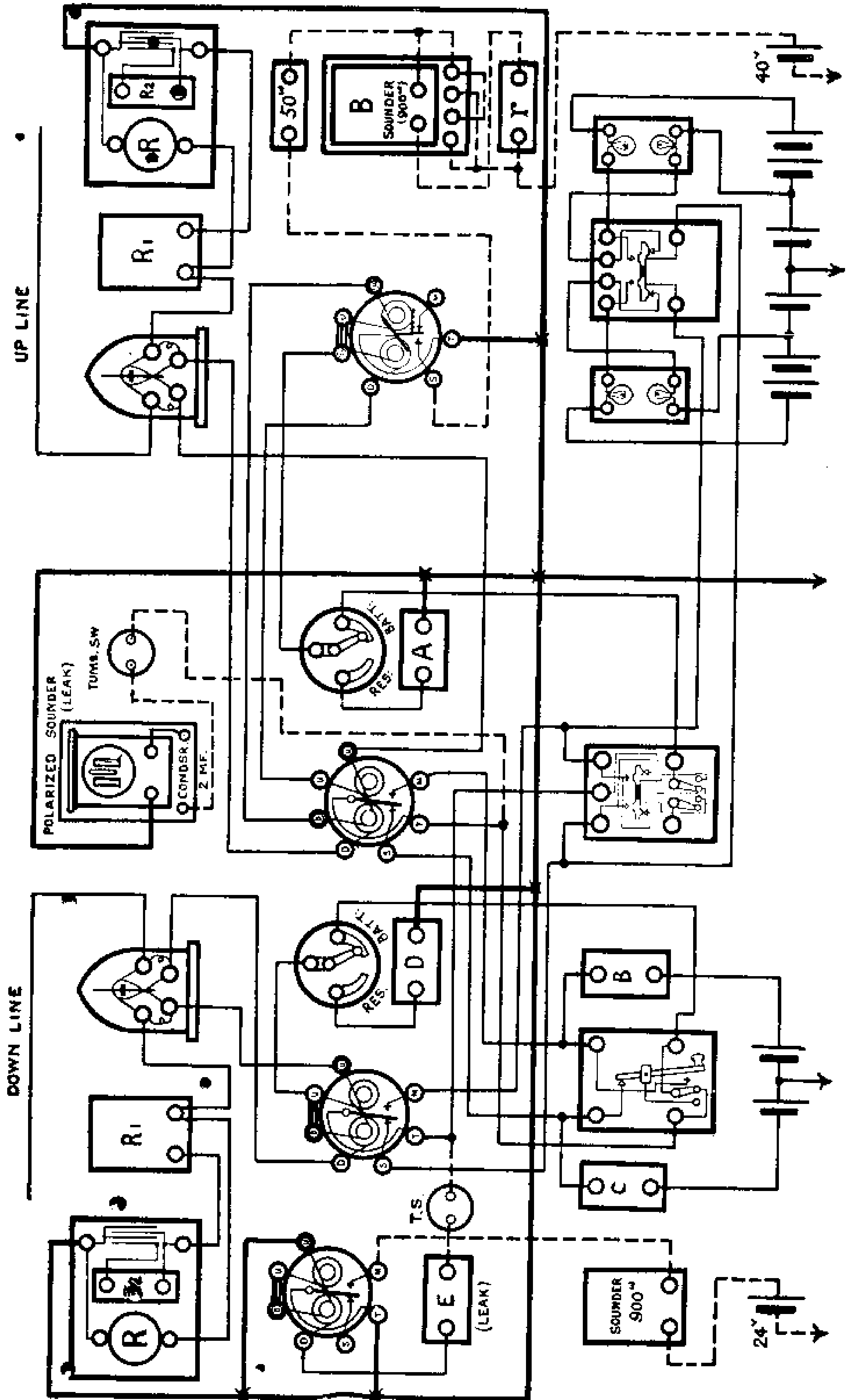


Fig. 191. Quadruplex: A side relayed.

Quadruplex, A Side Relayed.—Three stations are involved: X with quadruplex apparatus and Y with duplex work together (A side at X) through a duplex repeater at Q, whilst Q works duplex to X on the B side. The full connections are given in Fig. 191 showing leaks, speaking keys, &c., whilst a skeleton arrangement is given in Fig. 192.

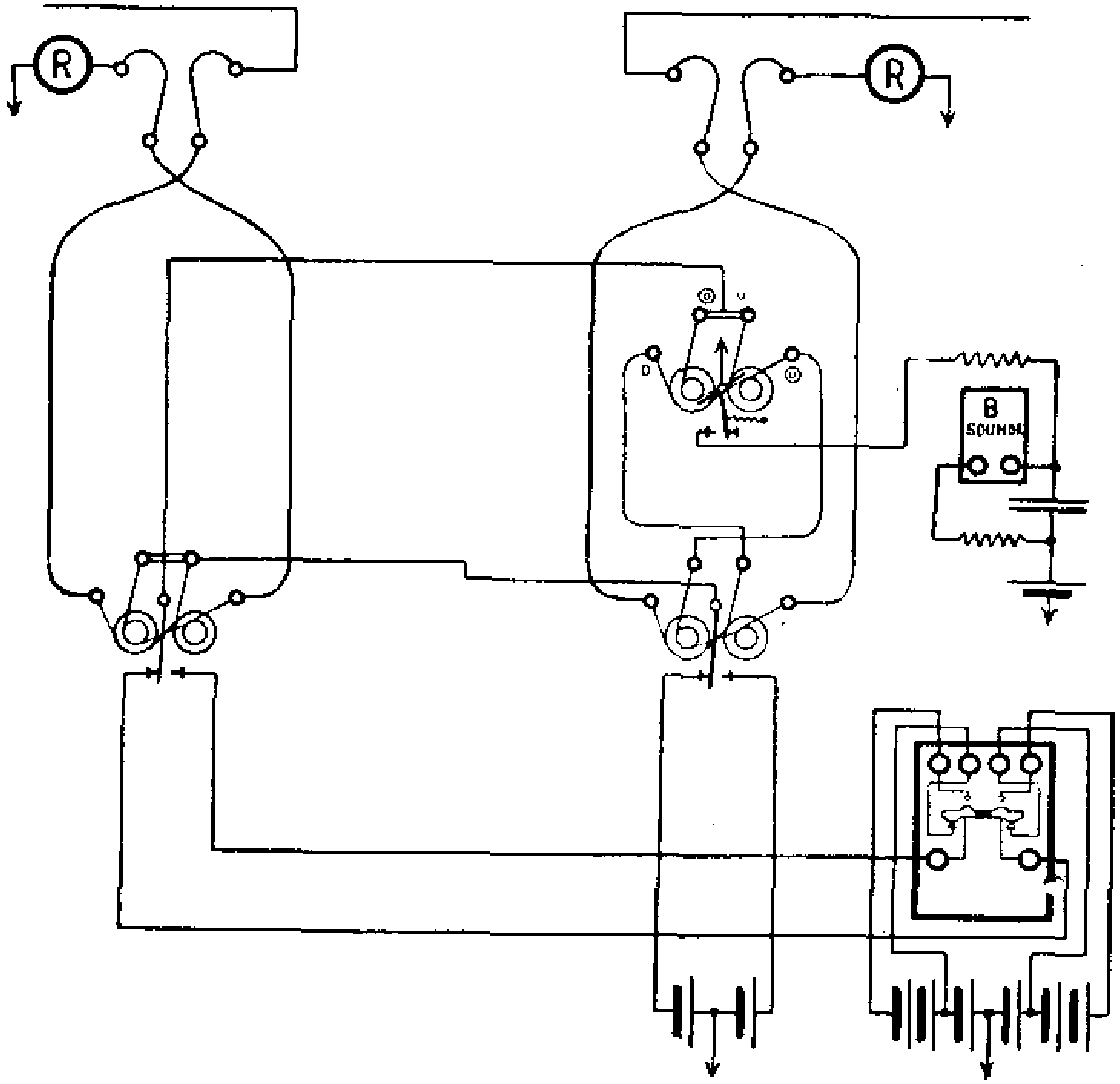


Fig. 192.—Skeleton of Fig. 191.

Sounder Silencer.—In a room containing many repeaters, as in a repeater station, the noise of the numerous sounders is very distracting—especially when it is remembered that if the circuits are working satisfactorily the repeater operator desires to know nothing more of them, but is only on the look-out for a possible "call" for attention on any circuit. It is a matter of some practice to get used to picking one's own code call out of a score of working sounders. To meet this difficulty the

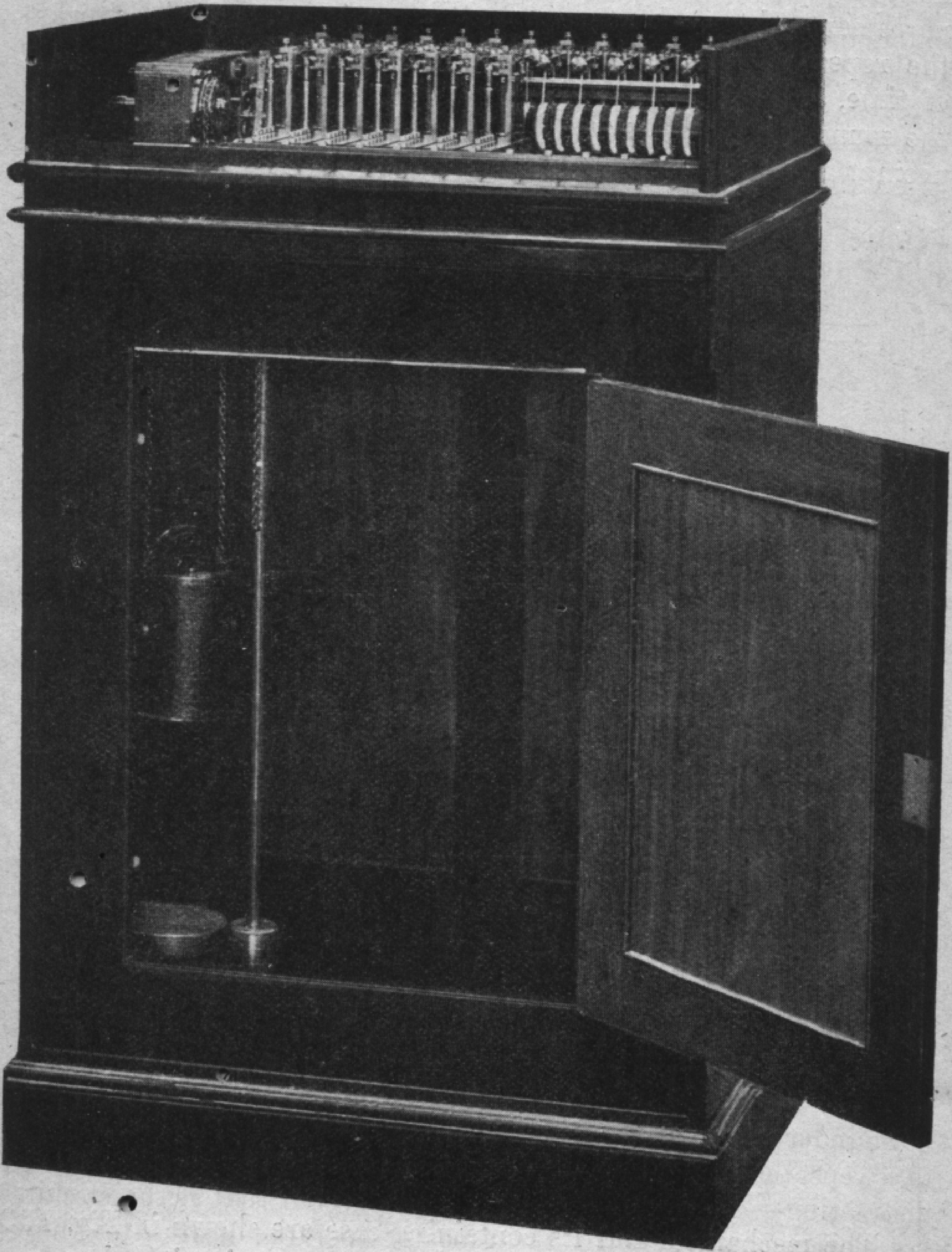


Fig. 193.—Sounder silencer.

"silencer" is devised. With this in use the repeater station is *normally perfectly silent save for the faint sound due to the* movements of the relay tongues. When a terminal office requires the repeater he holds down his key for a pre-arranged length of time, and this permanent current has the effect of bringing in *the sounder on that circuit.* The *call is thus at once heard* and prompt attention given.

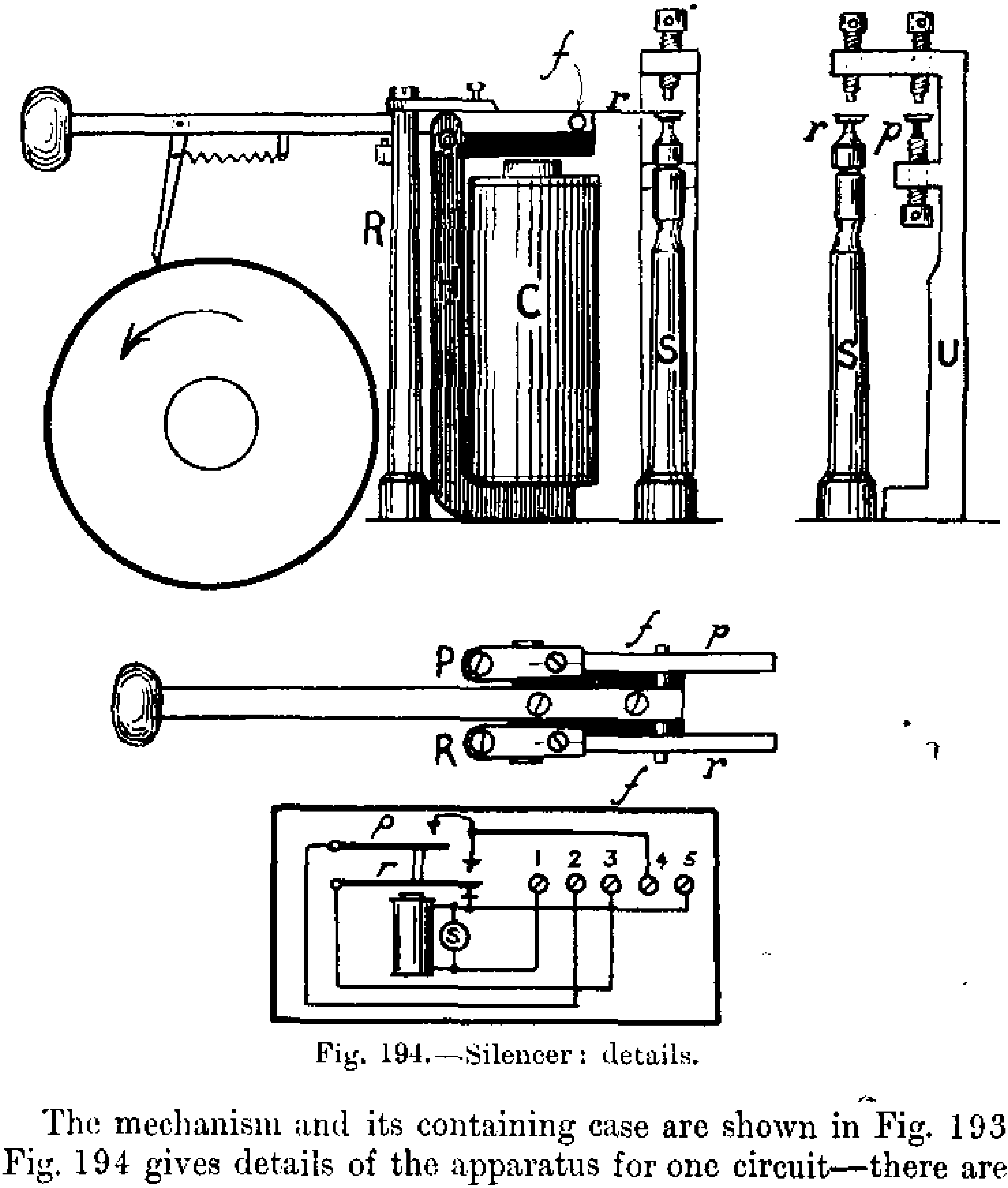


Fig. 194.—Silencer: details.

The mechanism and its containing case are shown in Fig. 193. Fig. 194 gives details of the apparatus for one circuit—there are, of course, a number of such sets, according to the capacity of the silencer itself. The first portion of this figure (194) shows the arrangement as seen from the side, the portion on the right as seen from the end, and the portion below these is a plan and a diagram.

C is a single-coil electro-magnet, its soft-iron yoke being continued upwards as shown by H. Pivoted in the end of this is a soft-iron armature, to which is fastened a long brass arm ending on the left in a brass bob or weight and carrying at the other end a couple of ivory pins, *f*, *f*. Two pillars, P and R, carry each a flexible contact spring, *p* and *r* respectively, and these are normally resting on the lower stops of two pairs of contacts carried by the pillars S and U. Further, beneath the left-hand ends of all the levers is a wooden cylinder continually revolving slowly in the direction indicated by the arrow. From each lever a small steel finger swings, its free end tending to be drawn to the right by the spiral spring shown. The distance between the uppermost part of the cylinder and the lever, however, is too small to allow it to pass further to the right than shown.

When no signals are passing and the tongues of the receiving relays are at rest, a permanent current passes through C and attracts the armature, thus raising the left-hand end of the lever to the position shown. Under these conditions, the surface of the cylinder is moving slowly under the end of the steel finger. The spring *r* is in connection with the pillar S, and the spring *p* is resting on the lower screw of U, which has an insulated end. The path of the permanent current is through the tongues and spacing stops of the relay and receiver.

When signals are passing, the connection with the spacing stop is necessarily broken, but the electro-magnet, being fitted with a shunt of equal resistance, is sluggish in letting the armature go. Further, the finger on the surface of the cylinder also tends to keep the lever in the position shown. When the armature is released this finger is free to follow the movement of the cylinder, and, as it moves to the left, the weighted end of the lever slowly falls until the finger can no longer grip the surface of the cylinder. It then falls, the two ivory pins lift the springs *p* *r*, and bring them into contact with U. In working, the fingers on the levers are continually making slight movements to the left, and are continually being withdrawn as the spacing contact is closed. When the calling station, however, holds down his key for the specified time (fifteen seconds), this interval is long enough to cause the finger to slip and the silencer to come into action.

Fig. 195 gives the connections between the relays and silencer: the first for primary batteries, and the second for secondaries. It will be seen that, in the latter, a third contact is provided on the lever of the silencer magnet, as also shown in Fig. 194. A press-button, with two buttons, is also included in the equipment. Normally, there is a continuous path through the fitting, between the two outer terminals. The depression of the "out" button throws the sounder out—*i.e.*, silences it—after a conversation. The effect of the depression of the "in" button is precisely the same as the continued holding down of a distant key, and brings in the sounder.

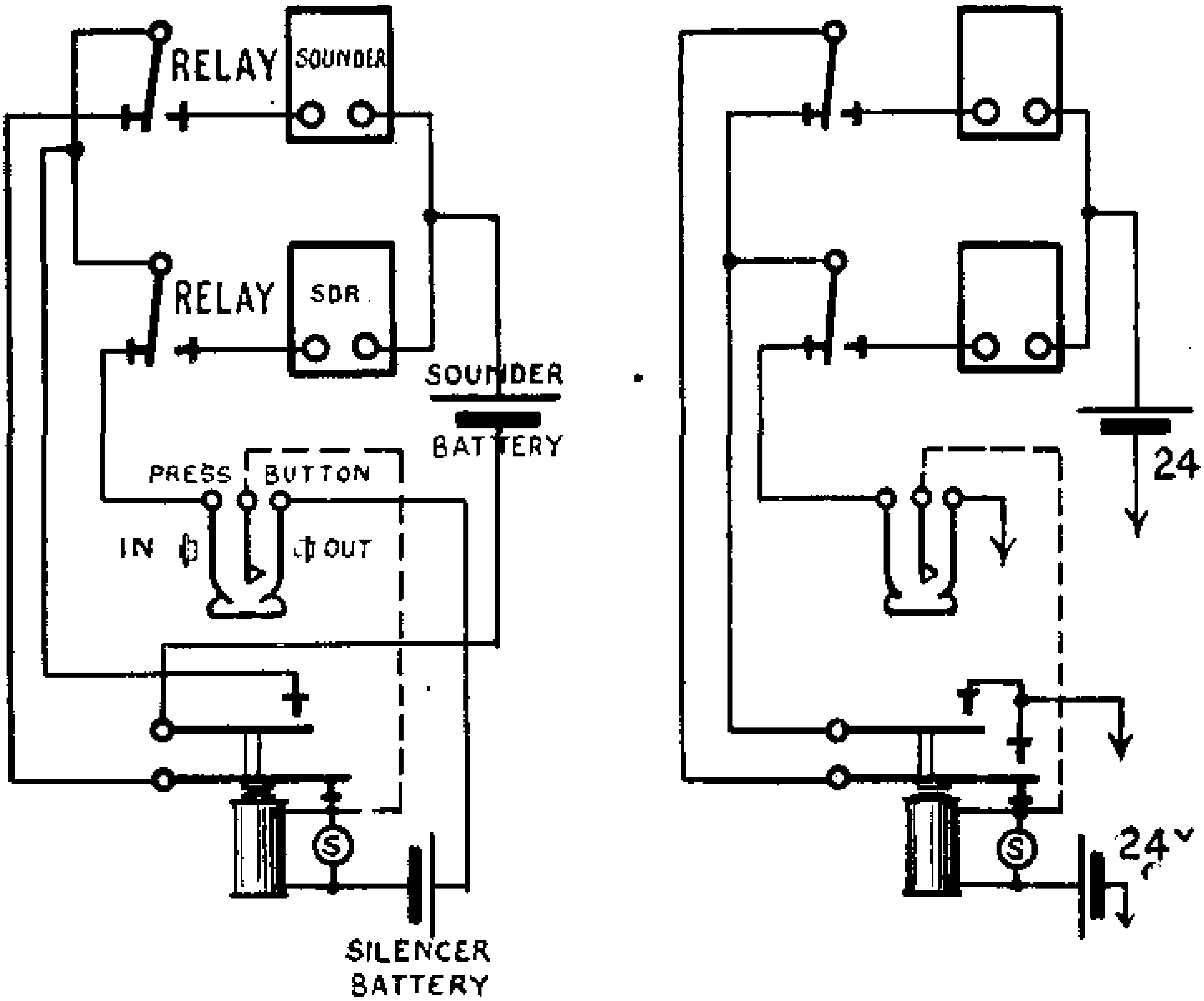


Fig. 195.—Silencer, connections: primaries and secondaries.

The silencer magnets being wound to 1,000 ohms and their shunts to the same value, the effective resistance of each combination is 500 ohms. Where secondary batteries are employed, the lowest voltage is 24, which gives a current of 48 milliamperes through each magnet, and this is flowing night and day. With many repeaters this involves a heavy drain upon the 24-volt sets

—although the magnets are divided amongst the positive and negative sets. To reduce this current, the shunts have been removed so that the resistance is that of the coil alone, 1,000 ohms. The sluggishness of the magnet being thus destroyed, the armature would rise immediately the relay (or receiver) tongue quits the spacing contact. A resistance coil of 3,000 ohms is, therefore, placed across these two terminals (S and T), so that when the tongue leaves the stop the current is not entirely cut off, but very much reduced in value. This is sufficient to bridge over the gap, and to prevent the release of the armature of the silencer magnet during the passage of working signals, but is not sufficient to retain it when the tongue is kept off permanently by a call. The two resistance blocks referred to can be seen fitted in Fig. 178.

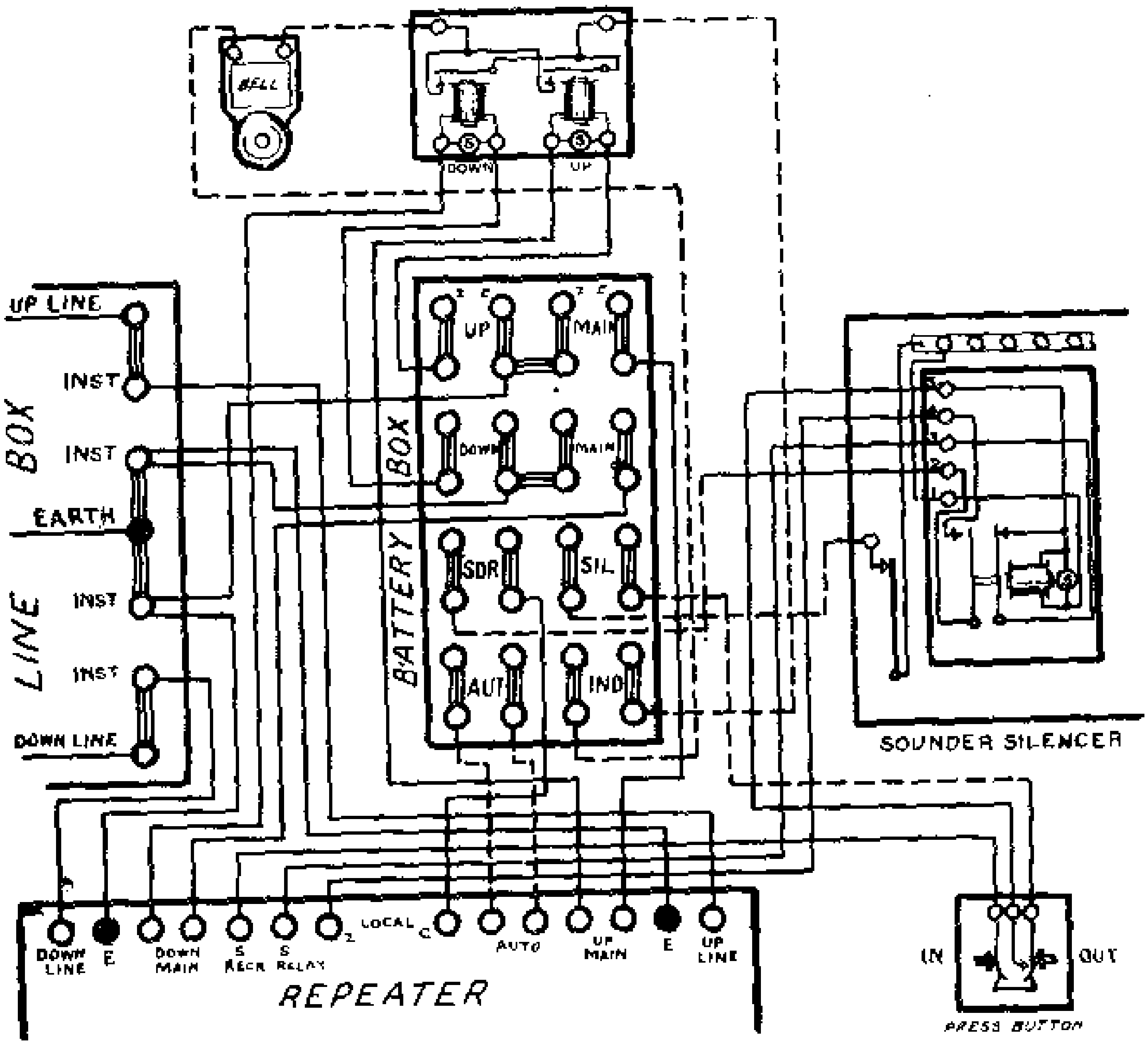


Fig. 196.—Test and battery-box connections: primaries.

Test and Battery-box Connections.—These are given in Figs. 196 and 197. The repeater board shown is the "double-decker" of Figs. 176 and 178. The first figure gives the arrangement where primary batteries are in use, with the old form of test and battery board. The second is the arrangement where secondary batteries are installed. The lines are terminated on a switch-spring board, as shown in Fig. 148. The power leads are brought to a combination consisting of a single fuse tablet like that shown in Fig. 150, and a table case (Fig. 151). From the latter, all the instrument tables are supplied.

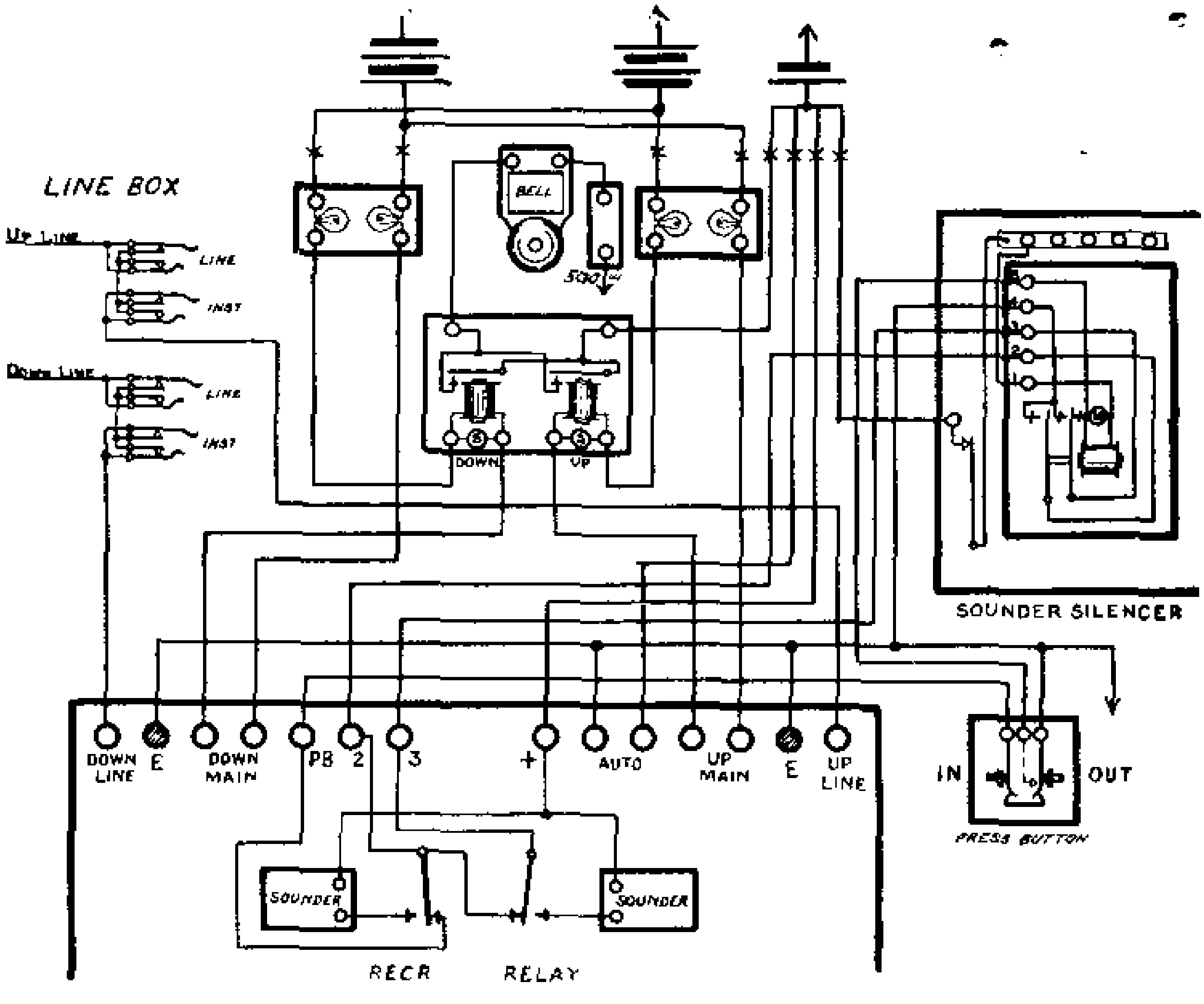


Fig. 197.—Line and battery connections: secondaries.

CHAPTER XIII.

SUBMARINE TELEGRAPHY.

THE special difficulties met with in submarine cable working, as compared with land lines, are those due to *capacity* or static effects.

With a perfectly insulated aerial line disconnected at the distant end, and having one pole of an earthed battery connected to it, it is easily seen that we have all the conditions of a condenser. The metallic wire serves as one coating or plate, the surface of the earth immediately beneath it as the other coating, and the intervening air acts as the dielectric. Increasing the length of such a wire is equivalent to enlarging one of the plates, and as the surface of the other plate—the earth—is correspondingly increased, the capacity of this natural condenser is increased in direct proportion of the length of line. Again, if we bring the line to a uniform height of, say, 10 feet, instead of 20 from the ground, we clearly decrease the thickness of the dielectric, and thus further increase the capacity. Or, if the wire be provided with an insulating covering, and is simply laid on the surface of the ground, its capacity will be very greatly increased, for the thickness of the dielectric will be reduced to that of the insulating covering. Underground wires thus have much greater capacity than open ones. Assuming the same size of wire throughout, let us imagine the insulated conductor to be submerged beneath the sea. For mechanical protection it will have a sheathing of iron wires over it. Its capacity under these conditions will be still further increased. For, when simply lying on the ground, only a portion of the conductor surface was active —viz., one "plate" being cylindrical and the other flat, that region of the circumference remote from the earth was practically non-effective. Beneath the water, however, the cylindrical conductor is surrounded by "earth." The water itself is in perfect connection with the earth, and by reason of its huge mass may be considered a good conductor; and, further, the iron sheathing completely encircles the cables. The system thus becomes a pair of cylindrical conductors, one consisting of the inner wire and the other the outer water, sheathing, and earth. In practice "earth" is always made by soldering a wire to the sheathing itself.

In a submarine cable, then, with its distant end insulated, we have a condenser whose capacity is very large compared with that of an aerial line of similar dimensions.

Imagine an earthed battery to be connected to the cable through a suitable galvanometer. The "earth," being made by the sheathing, we may consider the latter to form a second conductor, but of negligible resistance. At the instant of closing the battery contact a heavy rush of electricity takes place, say, positive going to the conductor and negative to the sheathing. After this heavy initial effect, however, electricity continues to flow into the cable, though at a very greatly diminished rate. With even a few miles of cable this is clearly seen; first, a heavy flow, then, not a cessation, but a steadily diminishing stream. With longer cables these effects become more and more prolonged. This is the operation of "charging" the cable. Its importance is seen in the fact that, when the cable is put to earth to complete the circuit for ordinary working purposes, this operation must necessarily take place before any current can appear at the distant end; and, further, at the end of each signal the reverse operation must be, at least partially, performed, of discharging the cable. The progress of a signal can be imagined. The (say) positive charge enters the conductor and the negative the sheathing. These travel along the length of the cable, attracting each other, and thus delaying their progress, until they meet at the distant end. The key being raised, the signal at the receiving end will not cease until the cable has fully discharged. If the sending end remains insulated all the charge must pass out at the distant end. It may be arranged to earth the cable at the sending end on the completion of the signal, in which case some of the charge will return.

If we compare the behaviour of a submarine cable, its distant end being insulated, with that of a condenser, we shall see that the charge and discharge of the former are gradual operations, whilst those of the condenser are practically instantaneous. This difference is due to the fact that, on applying a battery to a condenser, the whole area of the plates of the latter is at once available. In the case of the cable, however, the conductor resistance has to be encountered, stage by stage, and, further, the clinging effect of the charges on the conductor and on the sheathing, the total effect being the *retardation* of the cable. The greater the battery power used the worse these effects become. Hence, long cables are worked with the minimum of power, and the receiving apparatus has to be correspondingly increased in sensitiveness.

Reflecting or Mirror Galvanometer.—This instrument, the invention of Lord Kelvin, made submarine telegraphy commercially possible. In its simplest form, as shown in Fig. 198, it consists of a light circular mirror, having two or three tiny pieces of magnetized steel cemented on the back. This is hung in the centre of a circular coil by means of a silk fibre. A ray of light is thrown upon the mirror, and reflected upon a scale suitably placed, so that the movements of the spot of light can be seen. The direction of these movements depends, of course, upon the direction of the current—to the right or left of the zero position.

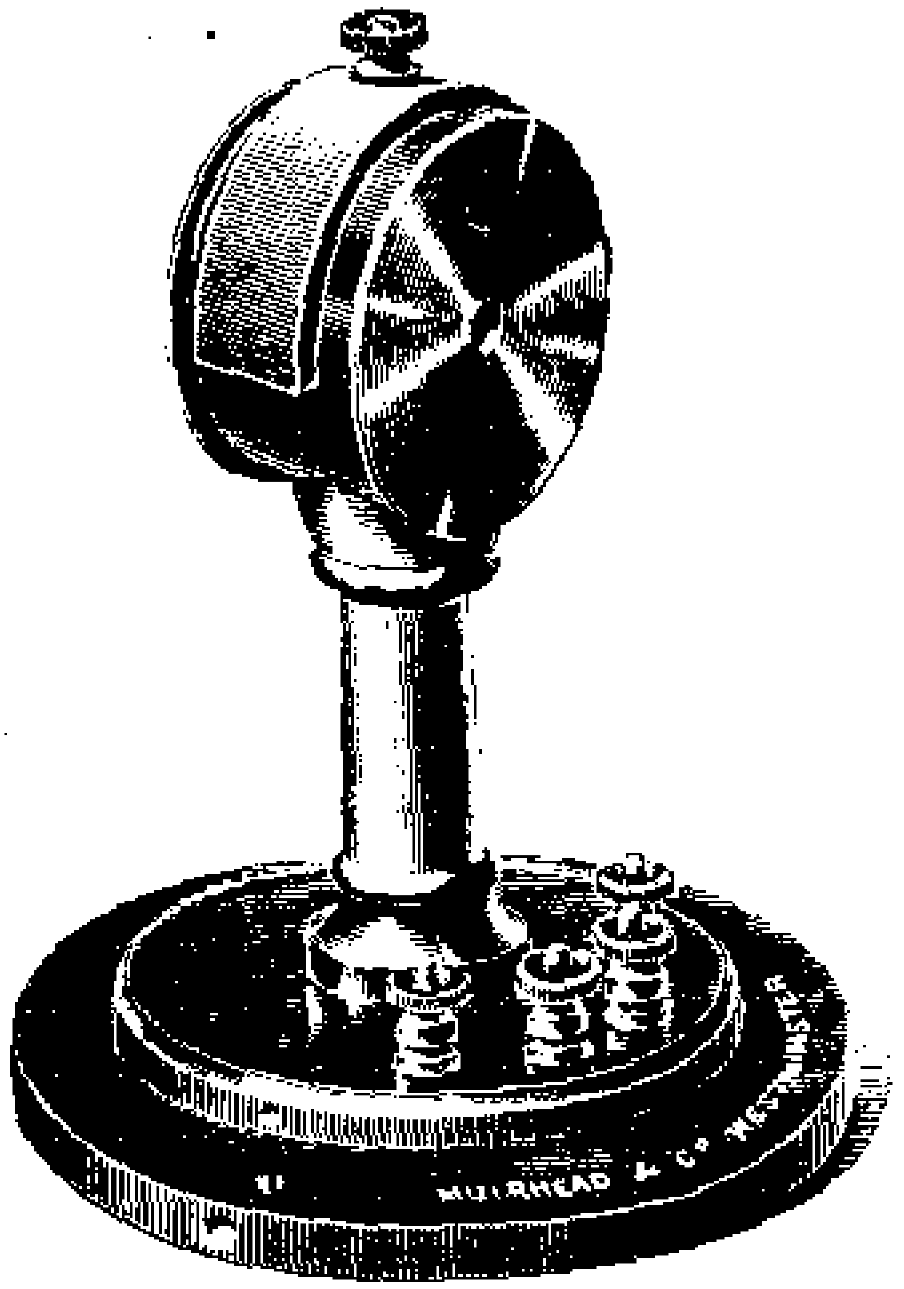


Fig. 198.

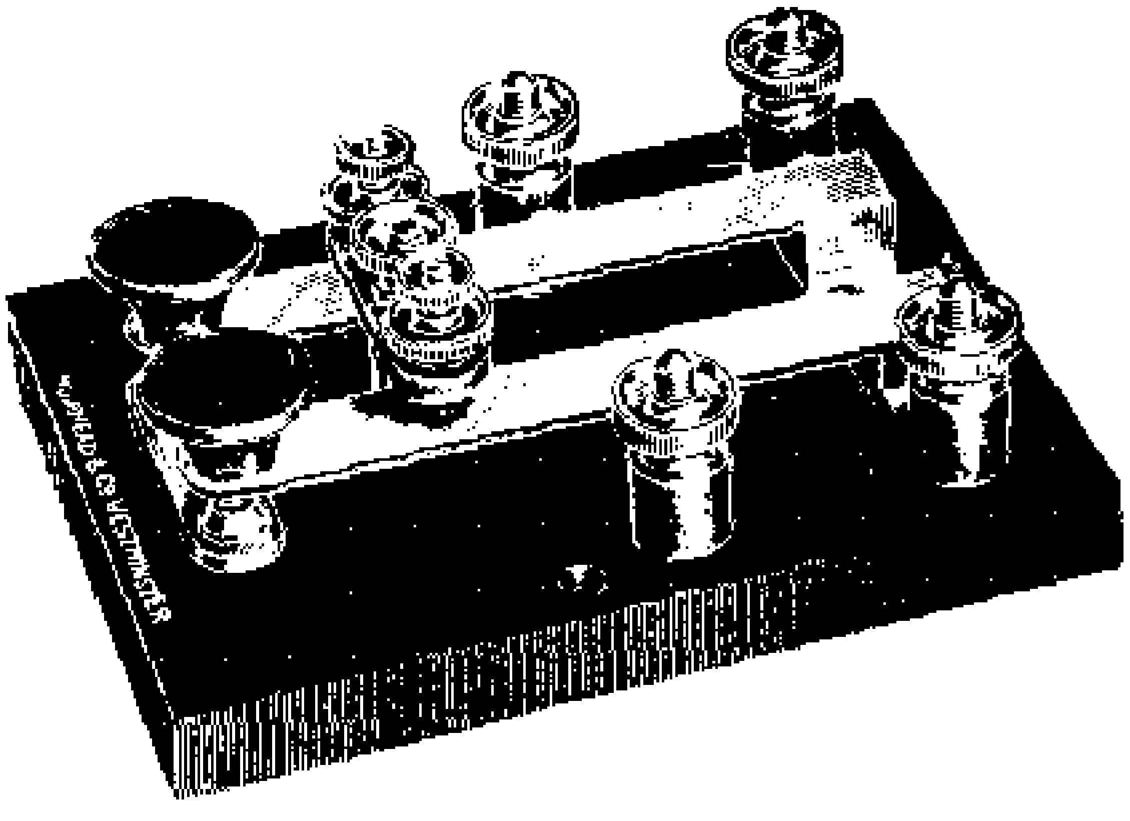


Fig. 199.

The sending portion of the apparatus is illustrated in Fig. 199, being a pair of tappers, somewhat on the lines of the single needle commutator, and used in a precisely similar manner.

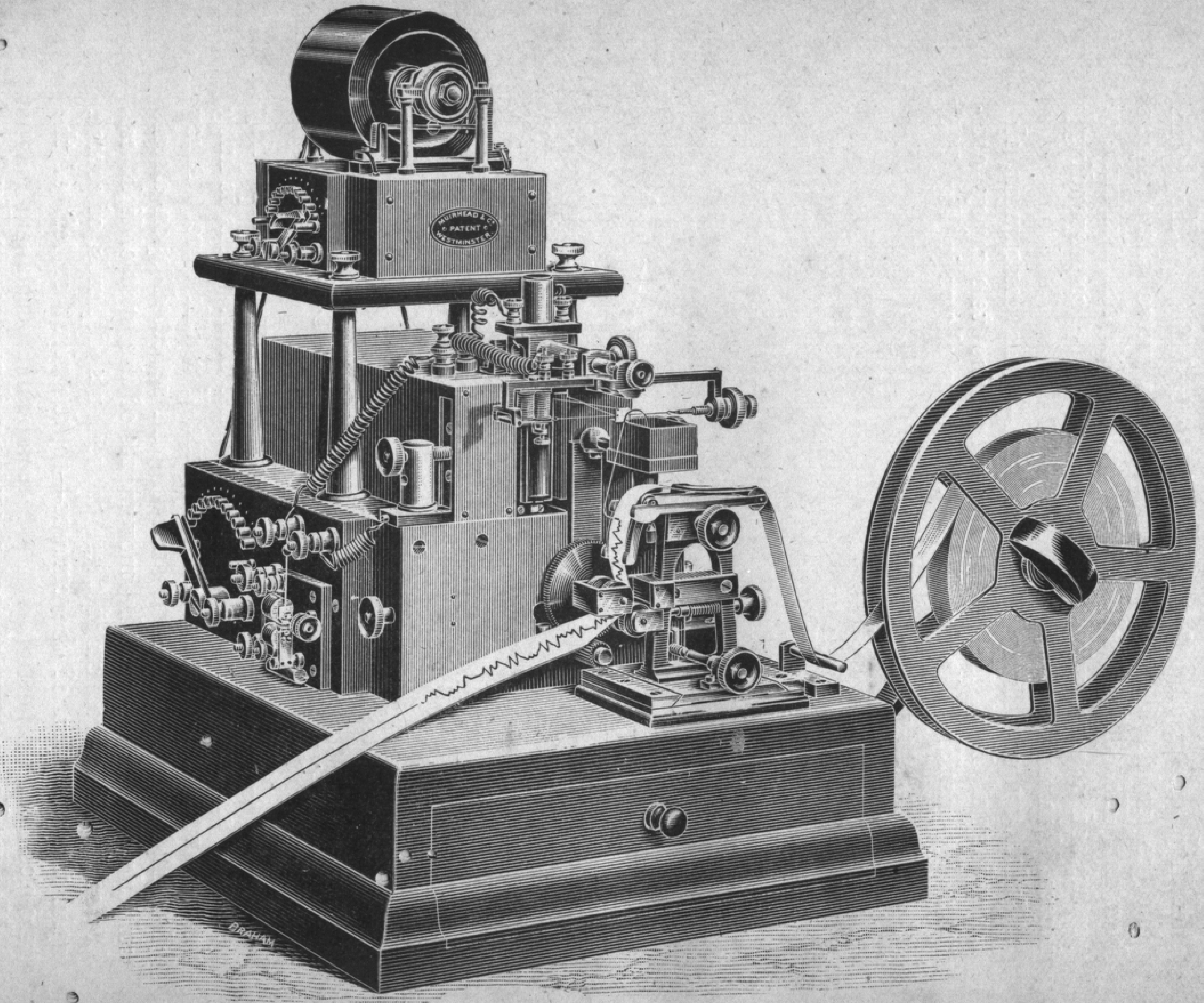


Fig. 200.—Siphon recorder.

When neither is depressed, the cable is to earth through the levers. The depression of one puts, say, positive to cable, and negative to earth, and the depression of the other has the reverse effect. The signalling, therefore, is on the same lines as that of the single needle.

Siphon Recorder.—The mirror instrument is now practically discarded as a receiver, excepting for speaking and other miscellaneous purposes, and the siphon recorder substituted. The mirror signals are transient and fatiguing to read, indeed, requiring one operator to read and another to write. The signals on the recorder are permanent, and the slip can be retained for reference.

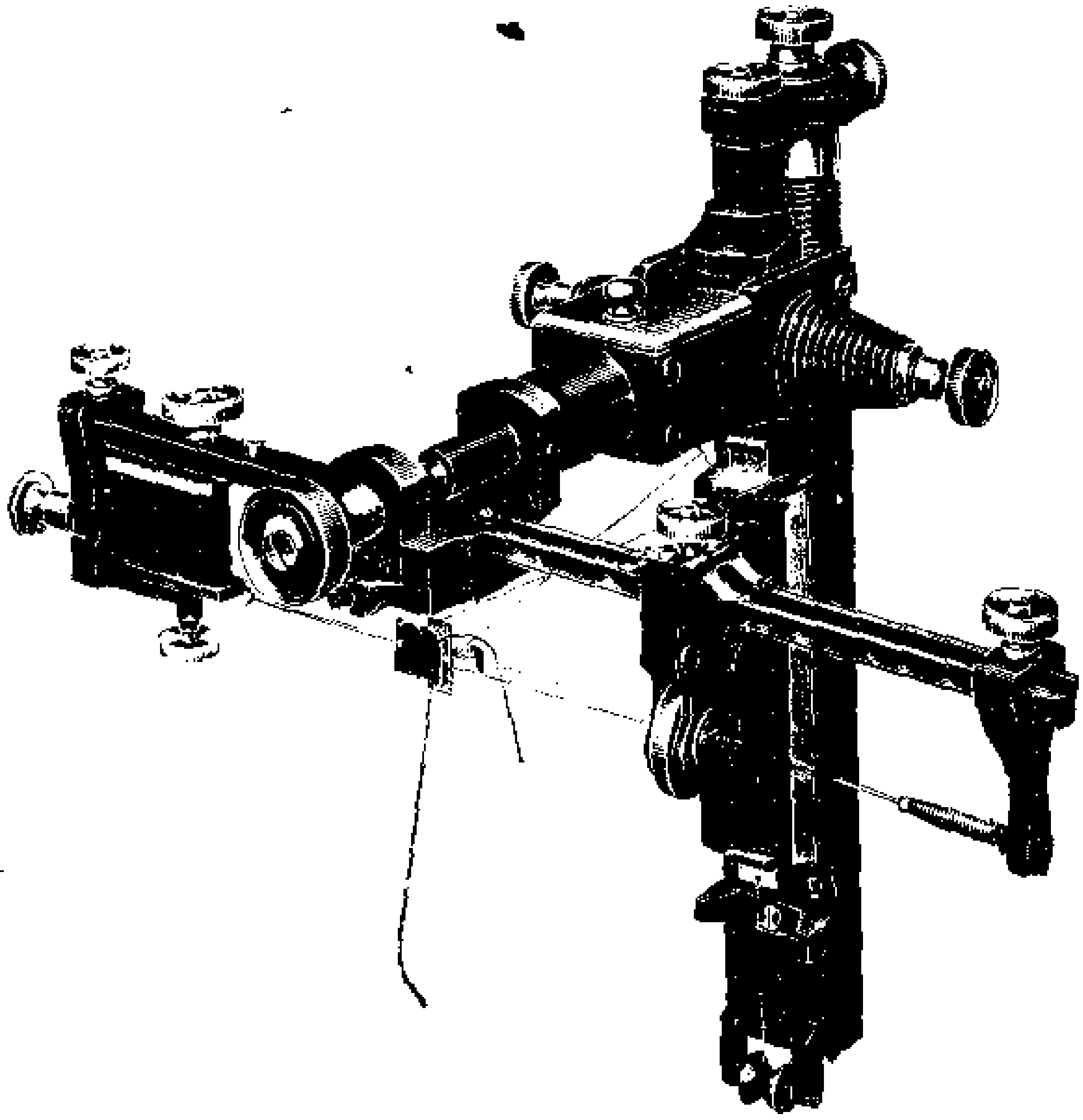


Fig. 201.—Bridge-piece of siphon recorder.

One of the most modern types is illustrated in Fig. 200.

In the central portion is a large compound permanent magnet placed horizontally, and in the space between its poles is suspended the signalling coil. This, with the bridge-piece and vibrator, is shown separately in Fig. 201. Across the bridge-piece is stretched a pair of fine wires carrying the siphon cradle—of aluminium. Two fibres are brought from the sides of the coil to the top and bottom of the cradle, so that the movements of the coil are communicated to the siphon. On the left, the two wires carrying the cradle are terminated on the end of the armature of a small electro-magnet. The latter is fed with intermittent currents by the interrupter seen at the left of Fig. 200, and shown in the diagram (Fig. 202). Hence, the siphon is kept permanently vibrating—its vibrations, of course, being

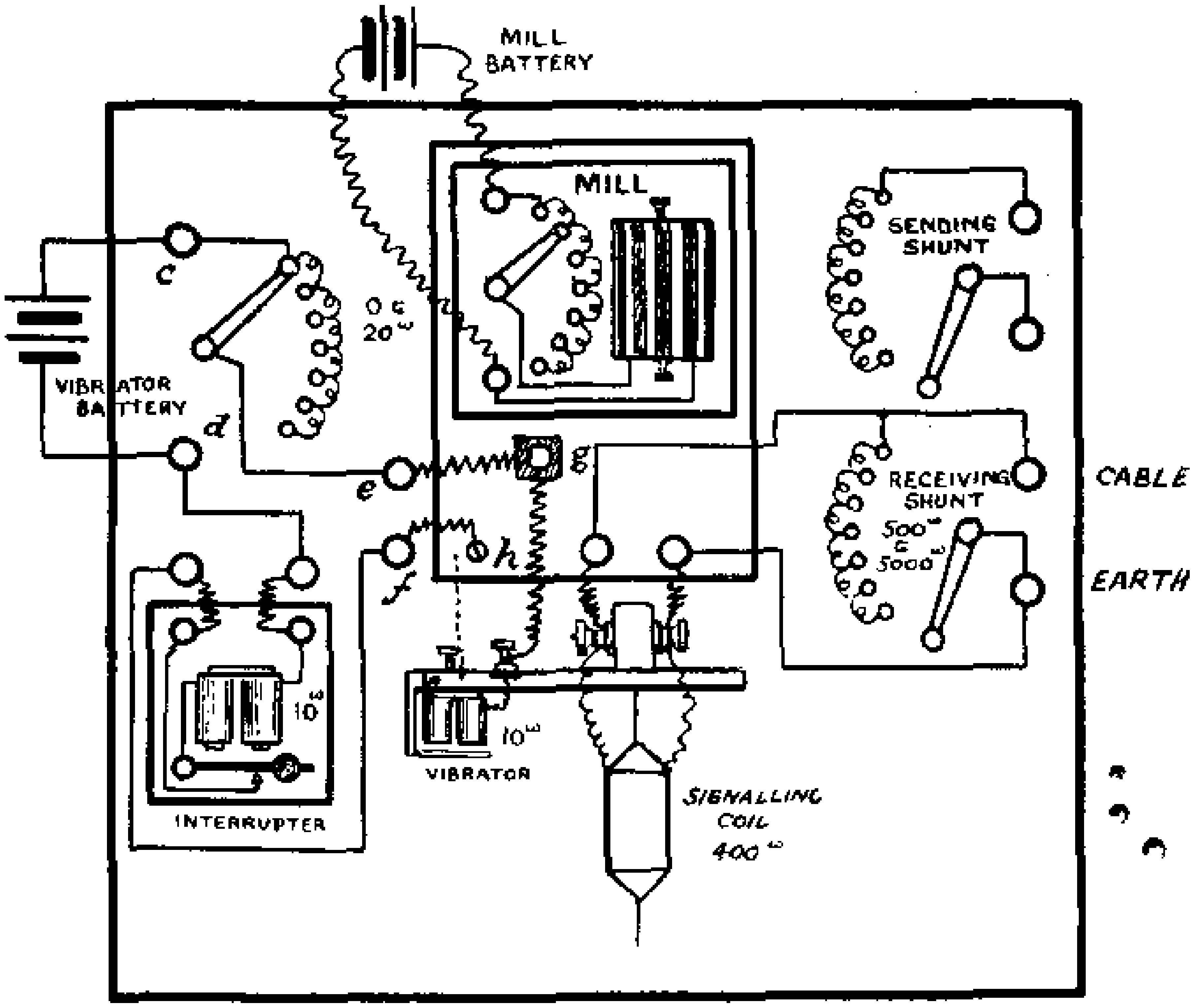


Fig. 202.—Siphon recorder : diagram.

very small—and the ink passes to the slip in a shower of tiny dots. If no signals are passing, these form a line in the centre of the slip, which is drawn off at a uniform rate by means of the "mill"—a simple form of electric motor mounted at the top of the instrument.

Received Signals—Curbing.—A specimen of received slip is shown at the foot of Fig. 203, but such a slip is ideal. It will be seen that after each impulse the siphon returns exactly to zero, and, further, that the amplitudes of all the impulses—*i.e.*, the distance from zero—are all alike. In practice this does not occur. With hand-signalling, and a mirror instrument as receiver, the zero is constantly shifting. That is, each signal is read, not by the movement of the spot of light to the right or left of a fixed zero, but rather by the direction of its movements from its last position. Suppose the spot to be exactly in the centre of its scale, to commence with, and the letter H to be received. The spot moves to the left at the first impulse, but this does not fully clear off before the second is received, and so on with the rest. The result is that the letter really consists of four movements to the right, with a bare attempt at a return to zero between one impulse of the next. Hence, at the end of the letter the spot of light is a considerable distance from the central position.

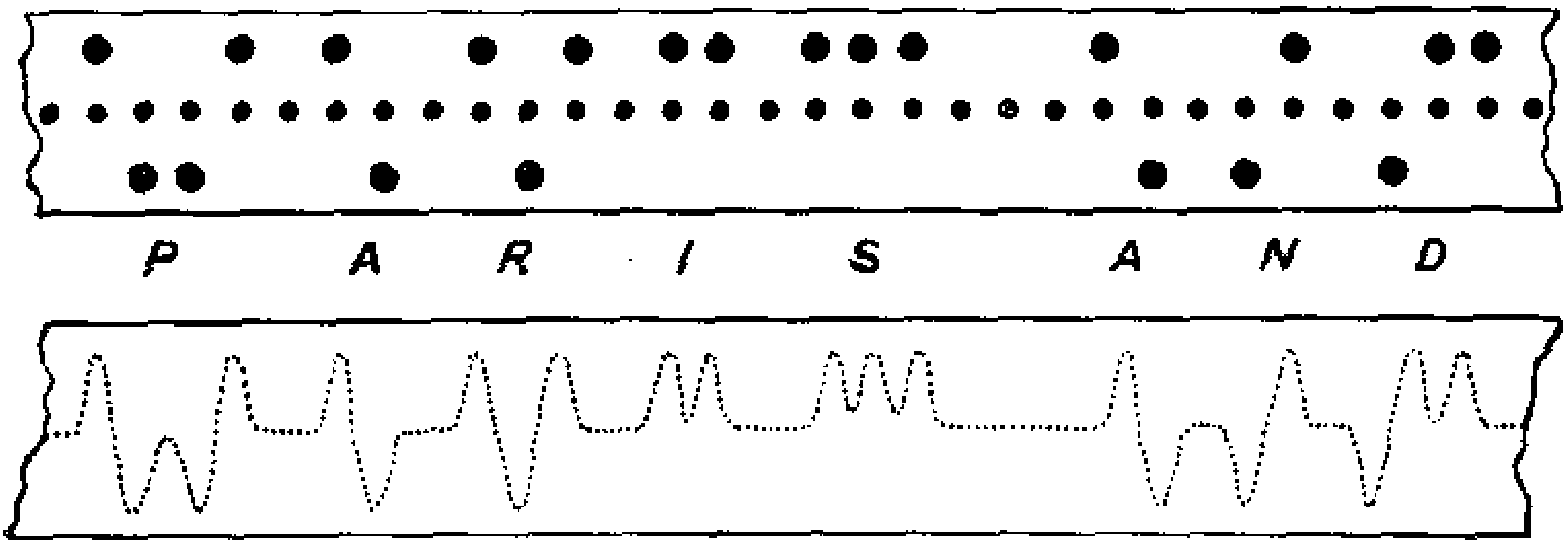


Fig. 203.

With a view to hastening the discharge of the cable between the signals, devices have been adopted by which a current of opposite sign to the working signal is sent to cable at the end of every such signal. This tends to clear away the preceding charge and to *curb* the signal.

Natural curbing takes place when the cable is worked by condensers—*i.e.*, a condenser inserted at each end of the cable. No continuous current can then flow, but the signals consist of impulses. This plan gives good, well-defined signals.

Automatic Working.—As the recorder has superseded the receiving mirror, so hand-signalling is now generally replaced by automatic means, which give signals of a uniformity and regularity unattainable by hand. The transmitter is frequently arranged to send a curbing current after each signal.

Perforator.—In general appearance this is like the ordinary instrument of Fig. 76, and its internal arrangements are similar. The depression of the middle (space) key punches a single hole in the centre of the slip. The left-hand (dot) key causes a central hole and one above it to be punched, whilst the right-hand (dash) key punches a central hole and one below it. This is seen in the specimen slip shown in Fig. 203. Thus the upper holes correspond to the "dots" of the Morse system and the lower to the "dashes," but the terms are not strictly applicable, as the signals are all of the same length, differing in direction only. Beneath the perforated slip in the same figure is the received slip.

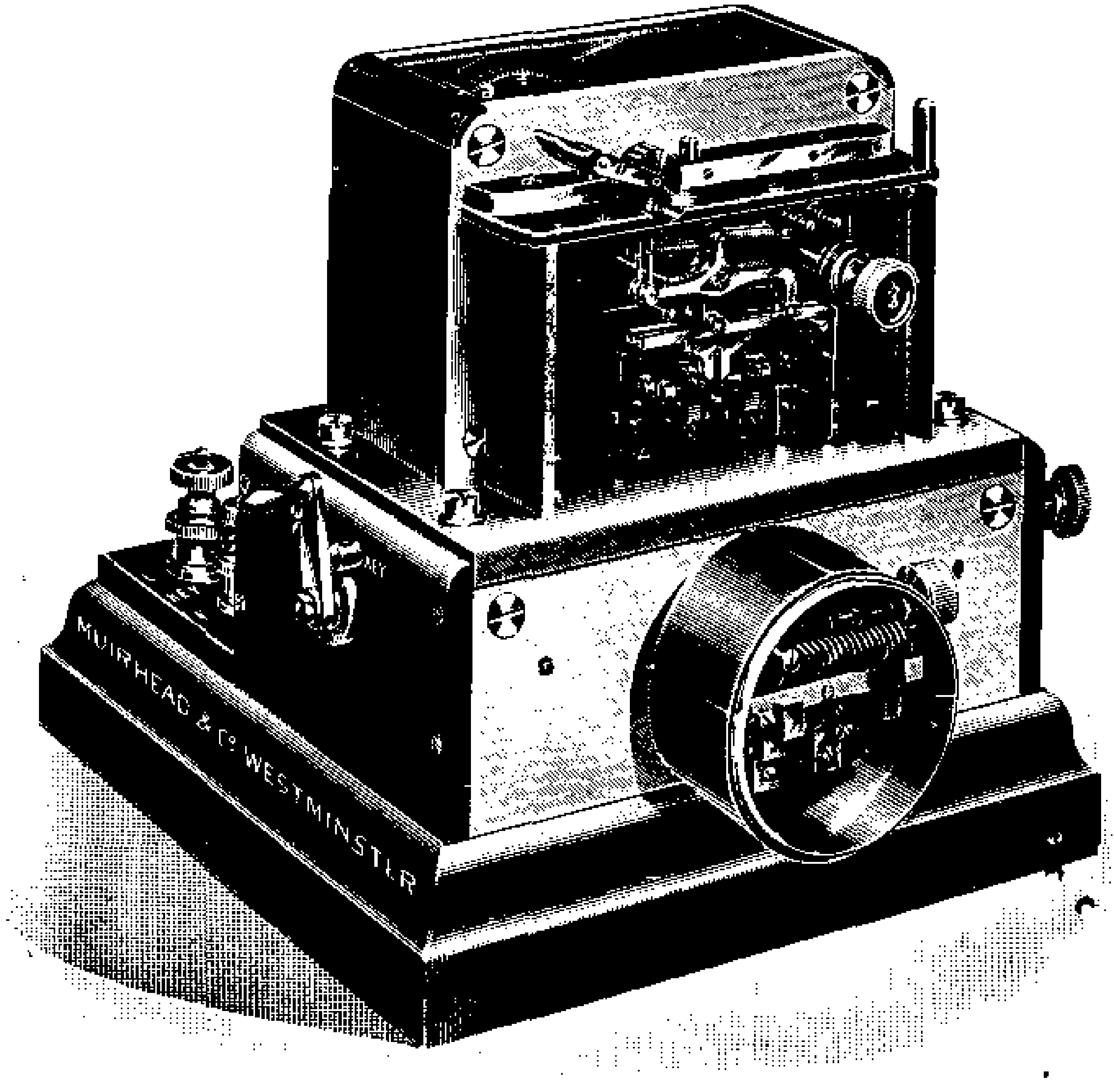


Fig. 204.—Automatic curb transmitter.

Automatic Curb Transmitter.—This is illustrated in Figs. 204 to 207, the first giving its general appearance. In Fig. 205, L_2 is a *contact lever playing between two contacts, x and y; there* are really two of these, but one is behind the other, and, therefore cannot be seen. By the pressure of two jockey-wheels these two levers must be on one contact or the other, never

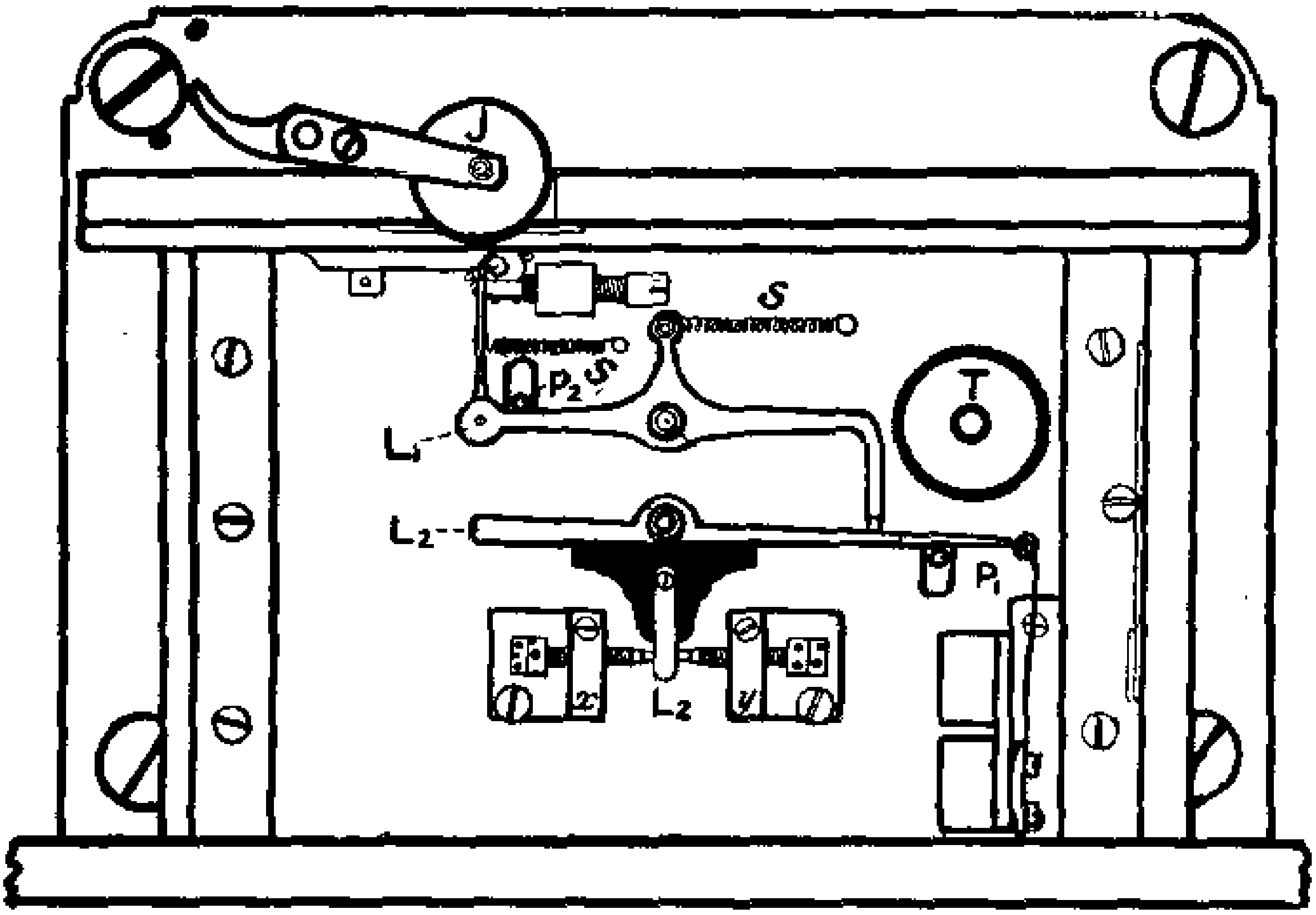


Fig. 205.

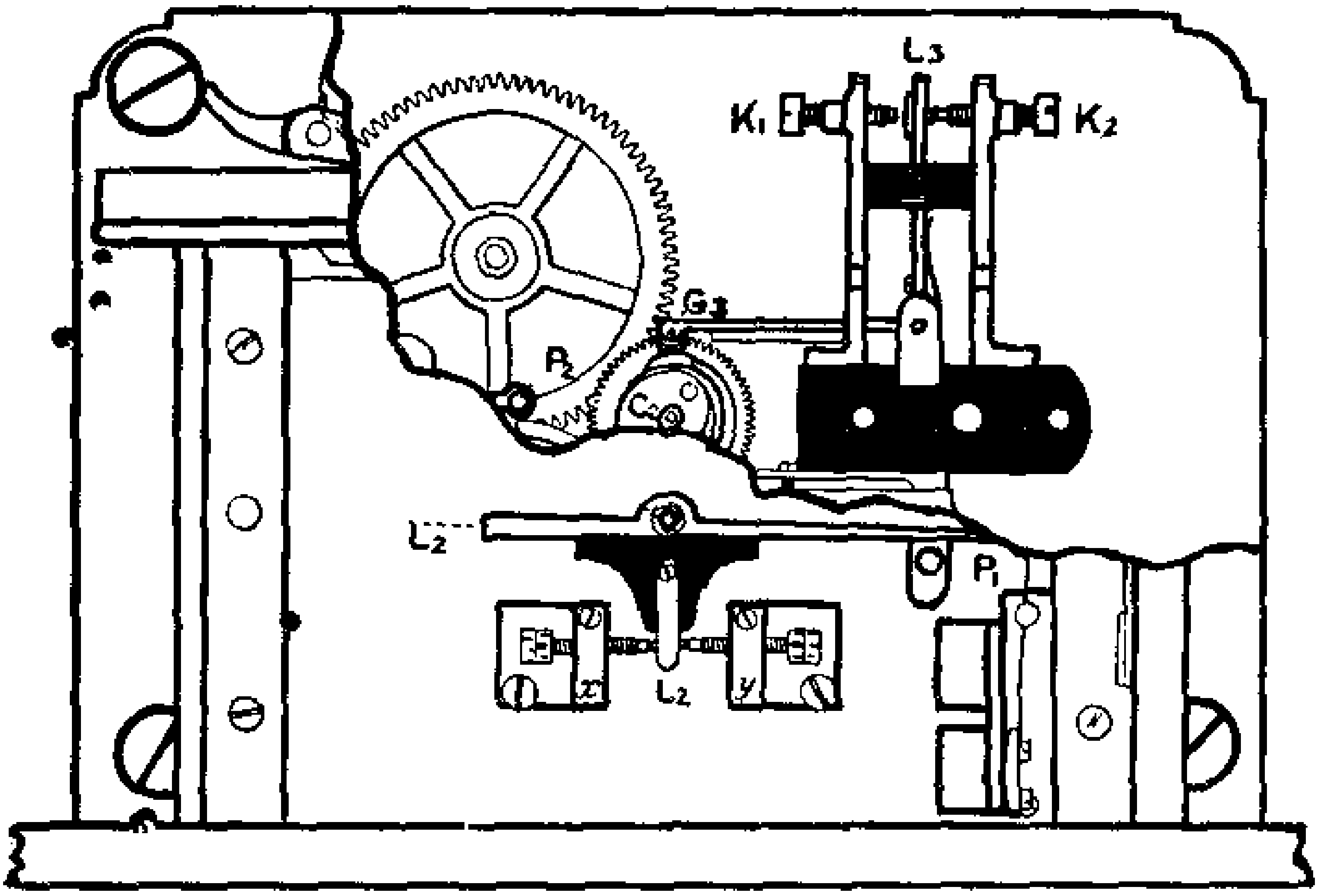


Fig. 206.

resting in the middle position. Above L_2 are two other levers, L_1, only one being seen, as the second is hidden by the first. The left-hand arms of L_1 each carry a vertical rod. P_1 and P_2 are two pins which rise and fall alternately with each other in two slots cut in the front of the instrument. The mechanism of the transmitter keeps these two pins in motion. Assume that the way is clear for the vertical rods to rise; when the pin P_2 rises the spring *s* causes both levers, L_1, to follow P_2. The right-hand ends of L_1 then push down the ends of L_2 beneath them, which the downward motion of P_1 allows. If, however, slip intervenes between the end of either, or both, rods, and the wheel J, one or both levers, L_1, will be unable to follow P_2 in its upward movement. Similarly, L_2 will be unable to follow P_1. From Fig. 203 it will be seen that the perforations are never such as to allow both rods to rise together, but always one or the other, or neither. Hence, when (say) a dot is punched, the back rod rises and the back L_2 lever is depressed, putting copper to cable. The zinc pole is already to earth by the front L_2 lever. This is best seen from Fig. 209, where the right-hand lever indicates the back L_2. When a dash is punched the front rod rises, putting copper to earth, the zinc going to cable *via* the other lever. When the

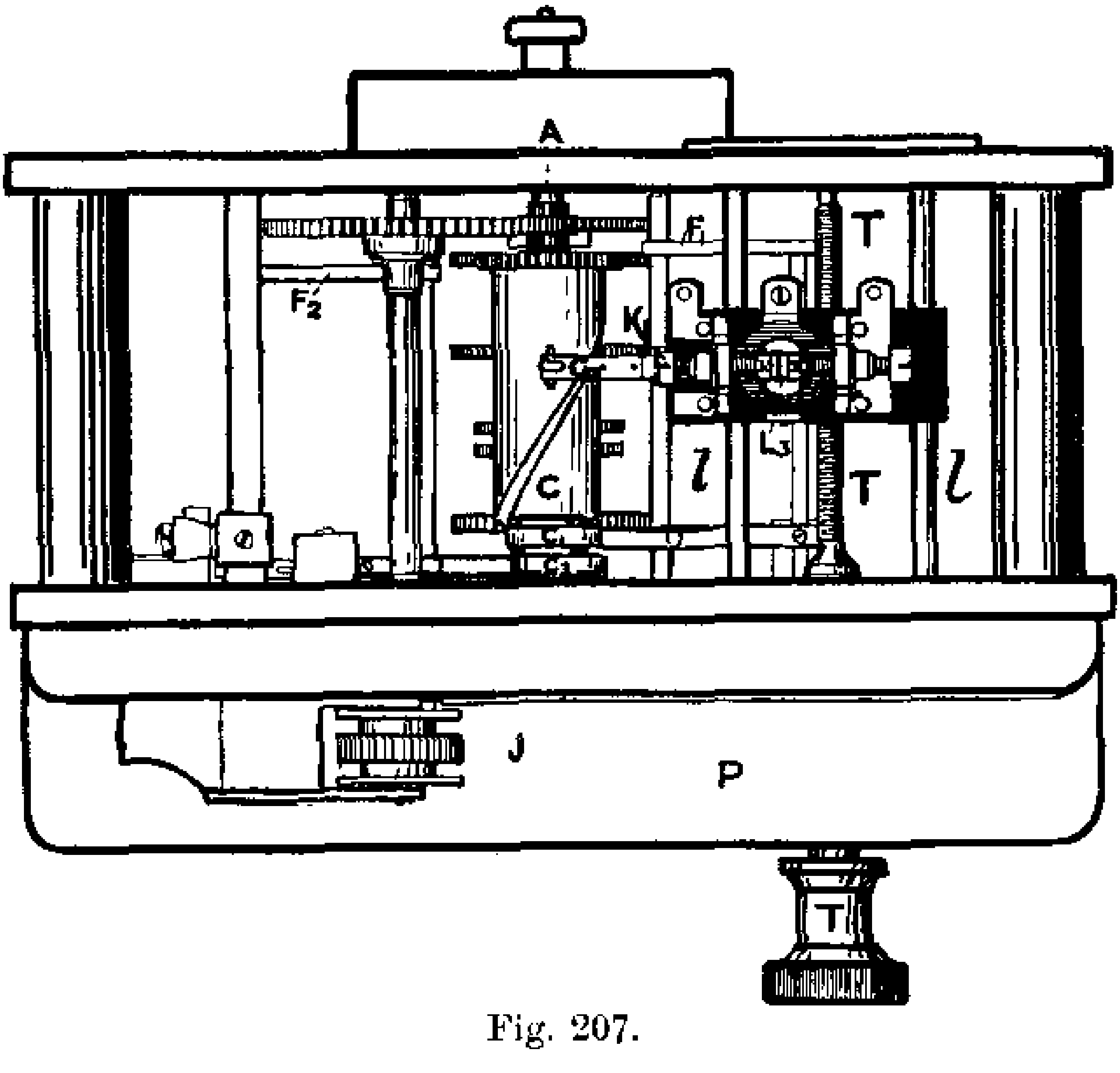


Fig. 207.

transmitter is running without slip both rods come up, but this has the same effect as their both being prevented from rising—no current is sent out and the cable is through to earth. When plain unpunched slip is run through neither rod can rise.

The curbing device is seen in Figs. 206 and 207. A vertical lever, L_3, plays between two contacts, K_1 and K_2. The lever has a horizontal arm, G_3, carrying at its end a small wheel. A spring tends to keep L_3 to the left and G_3 pressing downwards. A shaft, A, runs from back to front and carries three

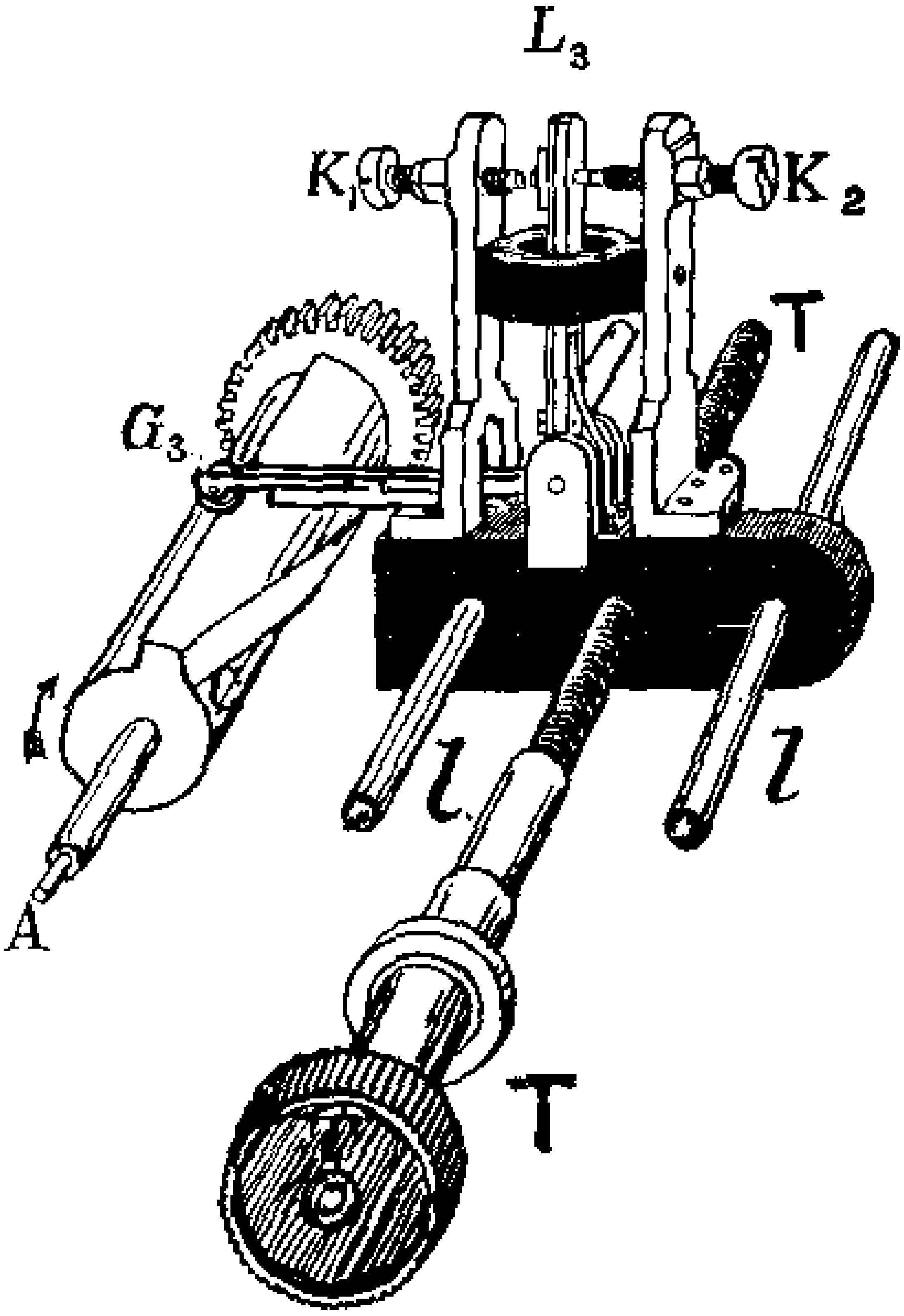


Fig. 208.

cams, C, C_1, and C_2. The function of the two latter is to keep the pins P_1 and P_2 moving up and down alternately. For each movement of the vertical rods the axle A makes one revolution, carrying round the cam C. When the cam arrives beneath it, G_3 is lifted and L_3 pushed over to K_2. The interaction of the lever L_3 with the levers L_2 is seen in Fig. 209 where it is resting against the left-hand contact K_1. Any movement of the levers L_2 results in the sending to cable of a current from the signalling battery. But before L_2 returns to its normal position the lever

L_3 is moved over by the cam C. This cuts off the signalling battery and substitutes for it the curb battery which thus sends out a current of the opposite sign. Every signal sent out is thus in two portions, the signal proper followed by a curbing current. It is necessary that the proportion between the duration of the two currents shall be under control. This is effected by making the carriage movable on which the lever L_3 and its contacts are mounted. The carriage is shown separately in Fig. 208, and its position in the transmitter can be seen in Fig. 207. The rods *l l* are guides on which the carriage runs. When the threaded spindle T is turned by its outer knob the carriage is moved backwards or forwards. The cam C occupies a considerable length of the axle A, gradually increasing in width towards the back. The farther backward the carriage is moved the greater the duration of the curbing battery contact and the less that of the signalling battery contact. The total of the two is always the same.

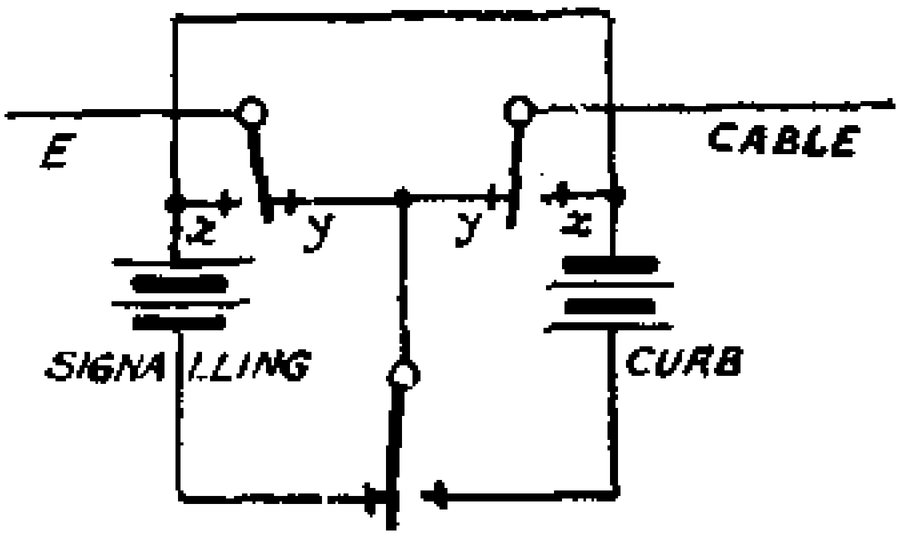


Fig. 209.

Connections.—The theoretical connections at one end of the cable are shown in Fig. 210. The cable is first brought by means of the condenser to a switch where it can be put to the sending or receiving instrument. The use of inductance coils to replace the condenser and to minimise the varying zero of the recorder has been suggested. This would be of low resistance and of high inductance and would be connected at the point *a*, its other end, of course, being to earth. Slowly-varying currents—such as earth currents—would choose the path of least ohmic resistance, but the more rapidly-varying signalling currents would pass through the recorder as the inductance coil would oppose their passage through itself.

Duplexing.—In the duplexing of long cables the bridge system is invariably employed. In ordinary bridge duplex (Figs. 92

and 176 to 178) the ratio arms or "duplex resistance coils" have signalling condensers of considerable capacity joined across them to hasten the rise of the current. In Muirhead's "double block," a system largely used on long cables, the condensers are retained but the resistances are removed entirely, the ratio arms thus consisting of condensers only. Another condenser is placed in series with the receiving recorder in the bridge. The practicability of duplex working, however, is entirely dependent on the artificial circuit. On a land line this can be a fair approximation to the actual circuit, but on a long cable worked by sensitive apparatus, the balance must be all but perfect.

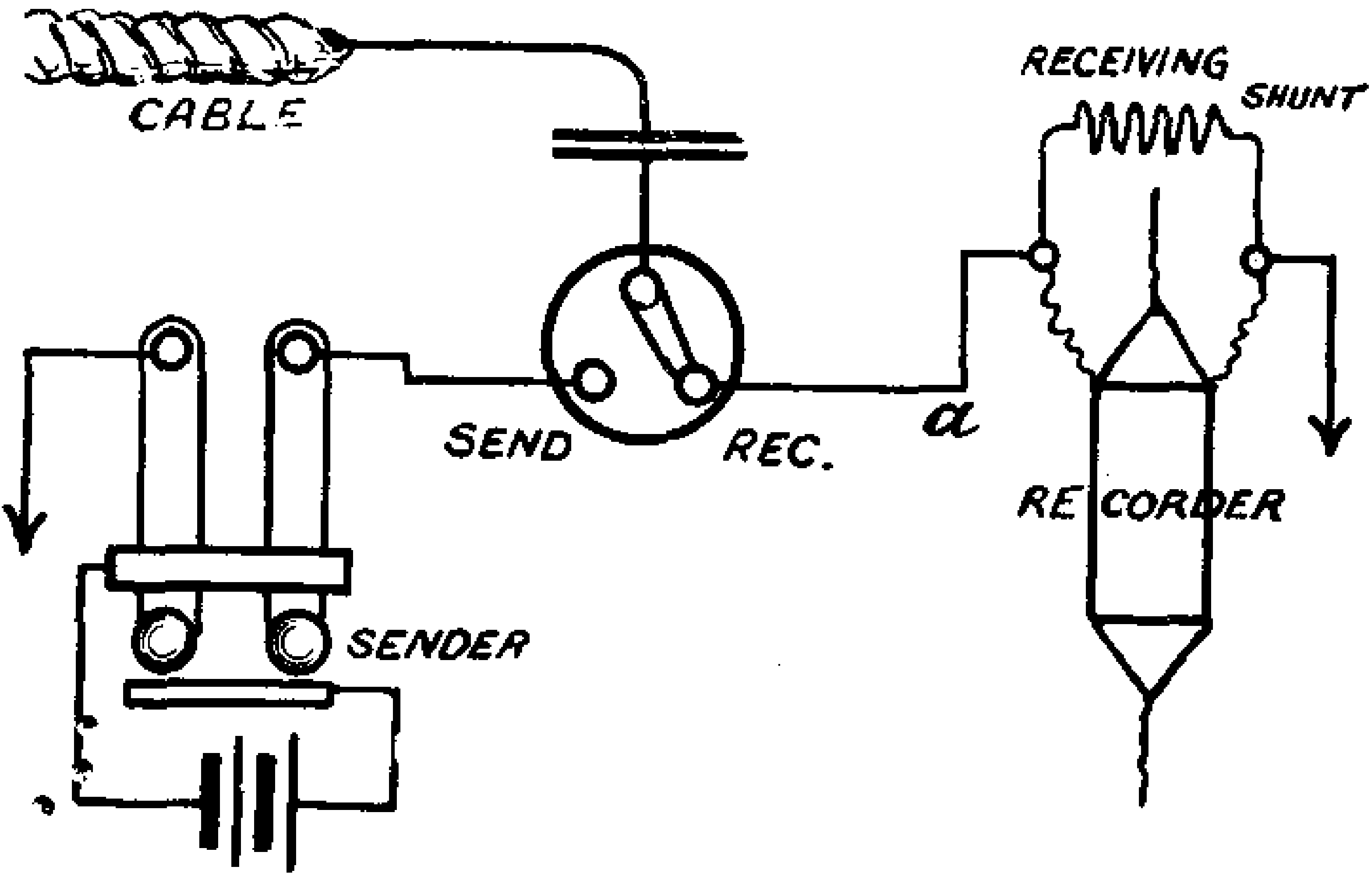


Fig. 210.

Varley's method of imitating the qualities of the cable consisted in cutting up the required resistance and capacity into a large number of equal parts. At the junction of each resistance coil with the next, one of the sections of the capacity was connected. This, of course, is representing a gradual rise by a series of short steps—the greater the number of steps the closer the approximation.

Muirhead's method imitates the qualities of the cable much more exactly, in that both the resistance and capacity are built up gradually and not in steps, however numerous. The principle is shown in Fig. 211. The shaded square is a sheet of tinfoil.

The larger square P P is a sheet of paraffined paper placed over the tinfoil. Above the paper is a zig-zag strip or gridiron of tinfoil, shown black. A large number of these are assembled as in making a condenser; first a plain sheet of foil, then paraffined paper, then a gridiron sheet, then paper followed by another plain sheet of foil, and so on. Each gridiron sheet has two ends or lugs, whilst each of the plain sheets of foil has but one. They are then connected up so that all the gridiron sheets are in series with each other and the single lugs of the plain sheets are all connected together. The gridiron set of sheets has thus two terminals, between which is a continuous strip of foil: this represents the conductor of the cable. The set of full sheets of tinfoil is brought to a single terminal and represents the sheathing.

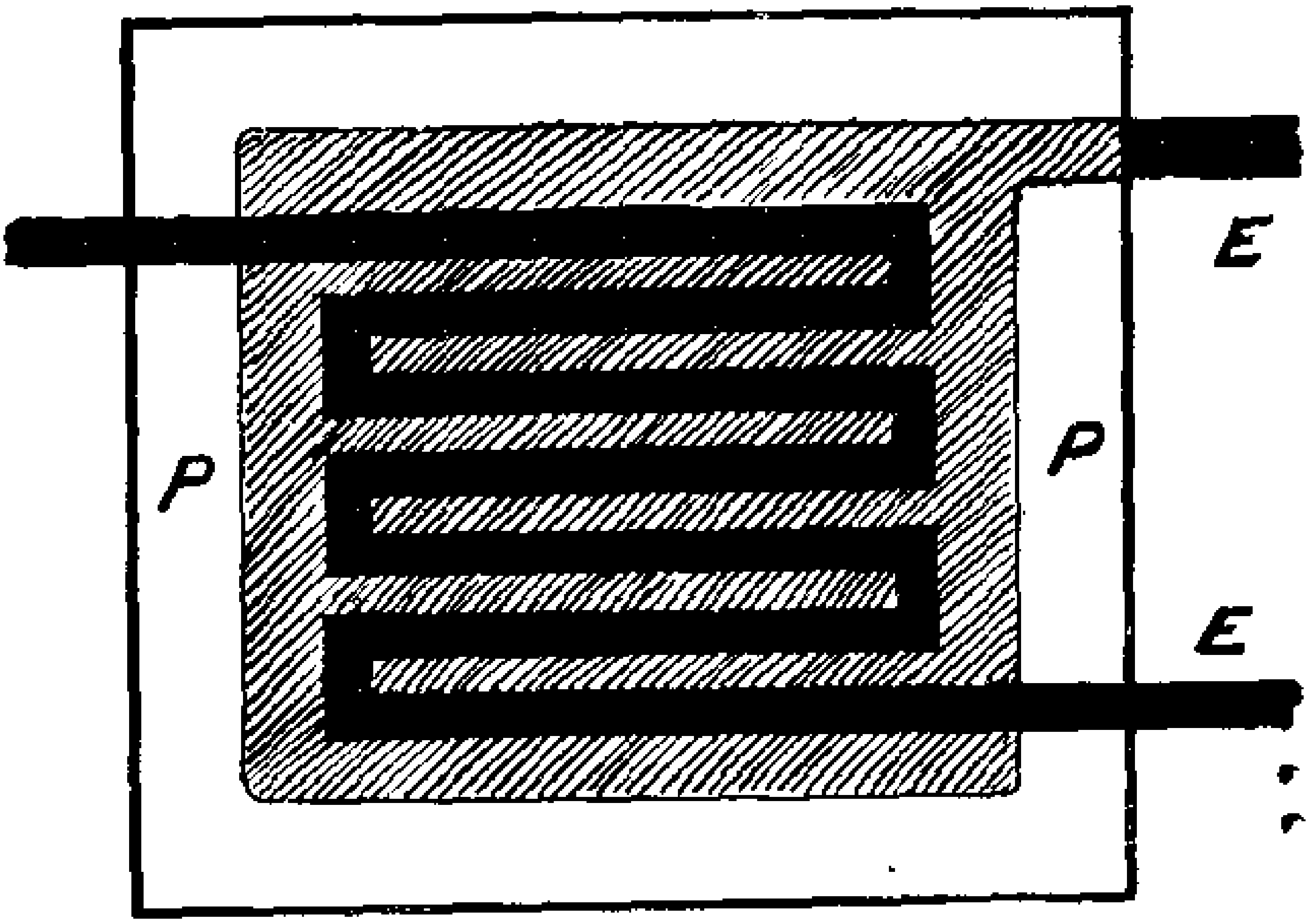


Fig. 211.

The resistance of the conducting strip depends on its thickness, width, and length: the capacity of the combination depends on the area of the strip. These dimensions are so chosen that for every fraction of the total resistance the same fraction of the total capacity is introduced. Suppose, for example, that the resistance to be represented requires ten of the gridiron sheets. (The number is, of course, absurd.) Each sheet will thus have that the condenser formed by one gridiron sheet and one plain sheet of tinfoil, separated by the paraffined paper, shall give one-tenth of the total capacity required.

An artificial circuit thus made up is not adjustable like the combination of rheostat, condensers and retarding coils representing a land line. But a submarine cable is practically constant, not being exposed to the variations and changes which occur on a land line. The changes which do take place are within comparatively narrow limits and are spread over long periods. By reason of its great bulk the artificial circuit is made up in sections, and slight alterations can be made in combining these, so as to compensate for the small changes in the balance. A theoretical diagram of connections for duplex working is given in Fig. 212. R is a rheostat of very low resistance.

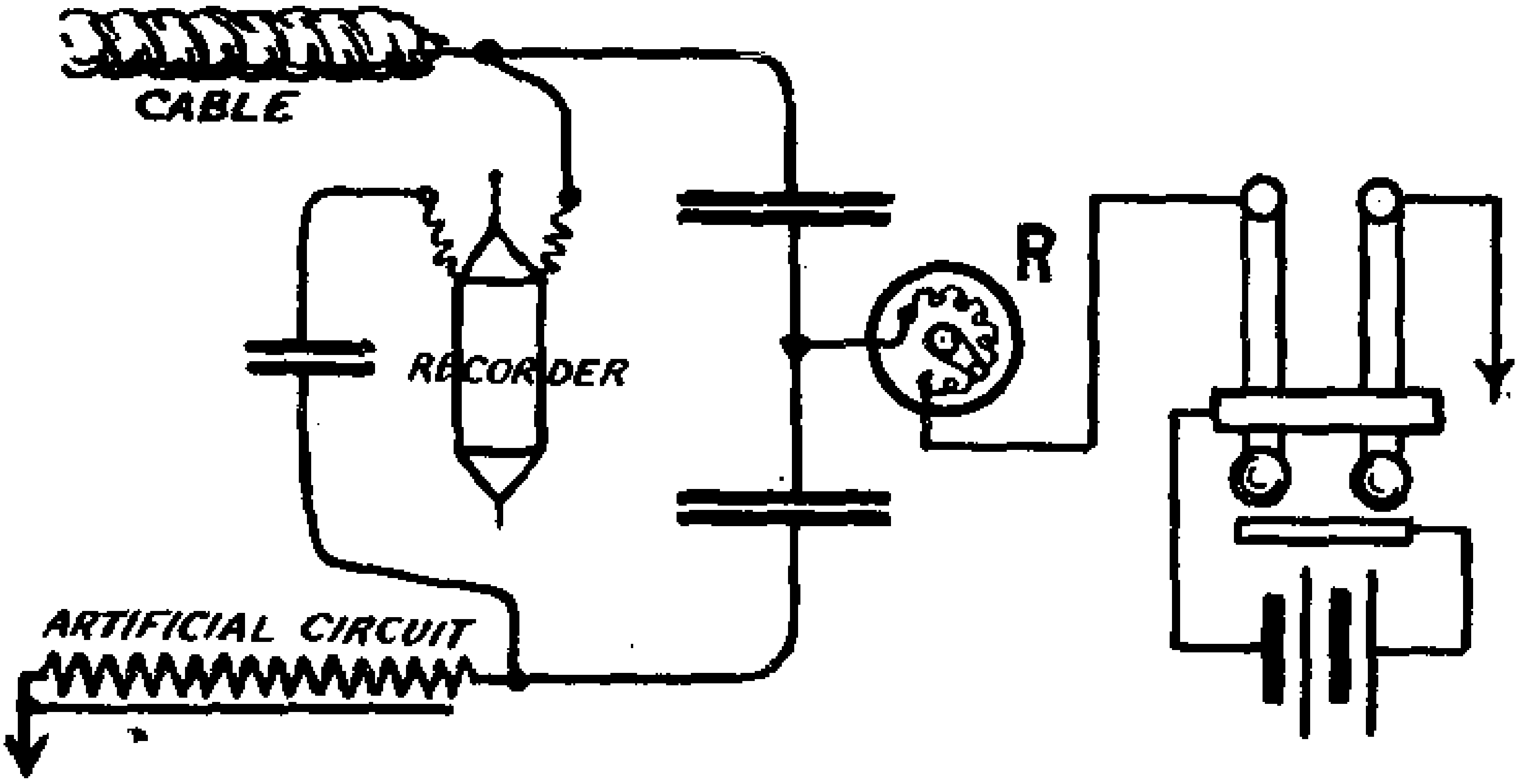


Fig. 212.

Repeating.—To design a satisfactory relay for repeating cable signals has been a difficult task. The signals received are so feeble that they are incapable of moving any but the most delicate apparatus. Fig. 213 shows the principle of such a relay—the Brown relay. C is a cradle carried by a horizontal fibre in a similar manner to the siphon cradle of the recorder, and connected by fibres, *f f*, to the signalling coil S. The movements of the coil are thus communicated to C, attached to which is a light metallic arm or tongue, T, whose end rests on the surface of the drum D, consisting of two conducting parts insulated from each other. T normally rests on this central insulation. The movements of the signalling coil cause the tongue to move to one side or the other of the insulation, and thus make contact with one or other conducting portions of the drum. Normally, with a fixed surface, such as obtains when D is at rest, the received currents would fail to move the tongue; but the drum is kept in continuous rotation. This has the effect of reducing the friction between the end of the tongue and the surface of D, and thus allows T to follow the movements of the coil.

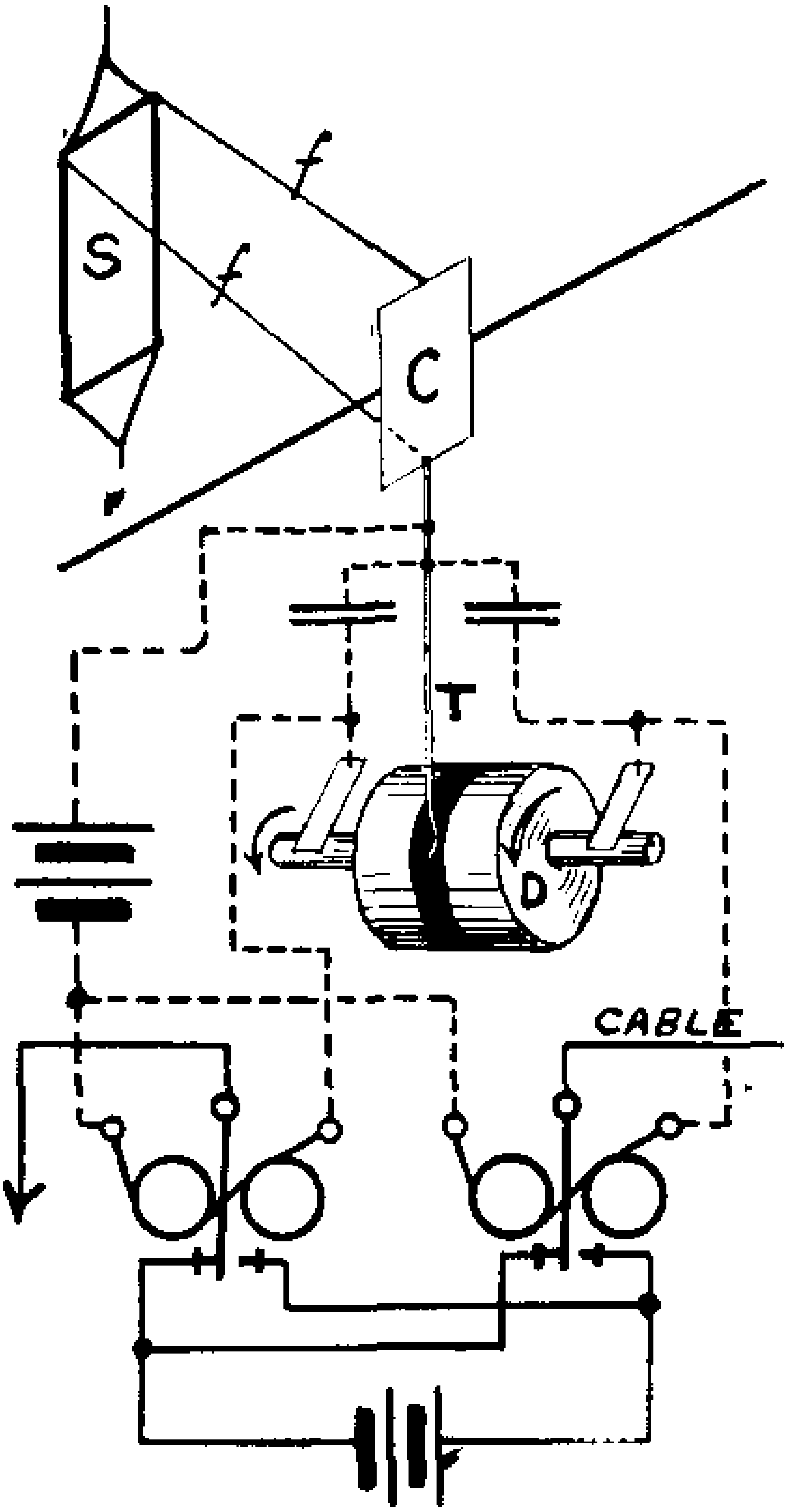


Fig. 213—Principle of Brown's relay.

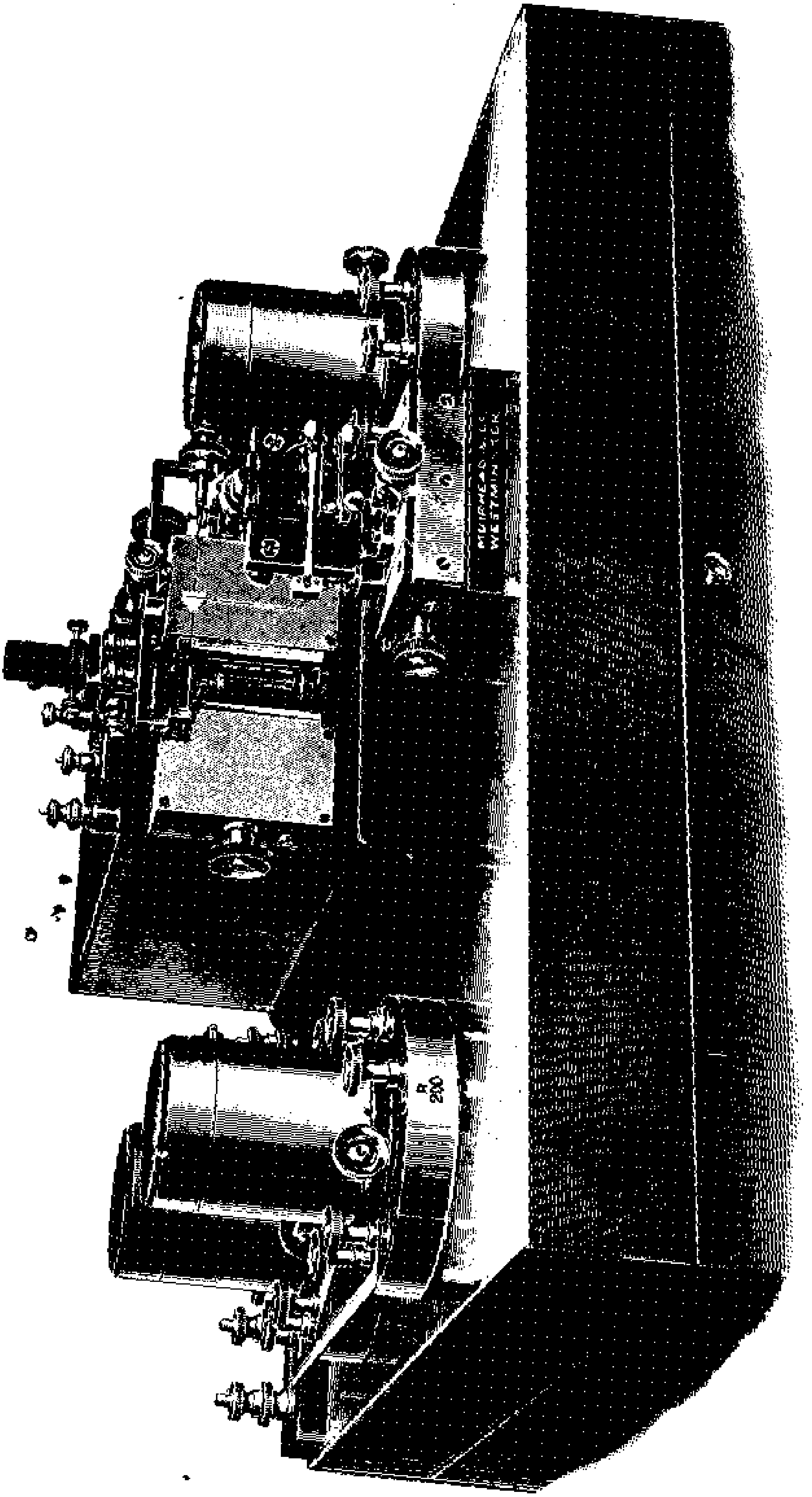


Fig. 214.—Muirhead's relay.

When T moves to the right, it completes the circuit of the ordinary polarized relay on the right, whose tongue then goes to marking, putting copper to cable. Zinc is naturally to earth through the tongue of the left-hand relay. A reverse movement of T actuates the latter relay, whose tongue puts copper to earth, the zinc pole being put to cable through the right-hand tongue. Both these relays must, of course, have a spacing bias.

The two condensers are to ensure good contact between the tongue T and the surface of the drum, the pressure of the former on D, naturally being of the lightest possible character.

We still have the difficulty of the running together of signals; that is, in the reception of the letter H, the coil may not reach zero between the impulses. In this case, the tongue T will remain on the right-hand portion of D, and an unbroken current, equal in length to the sum of the impulses, will be sent to cable by the right-hand relay. To split this up into its four constituents, special additional apparatus is employed.

Fig. 214 illustrates the complete equipment of a Muirhead relay for repeating. It will be seen that the tongue, in this case, moves over a surface formed of two plates separated by insulating material. The arm carrying these plates is kept in vibration (up and down) by the electro-magnet shown just above it.

CHAPTER XIV.

WIRELESS TELEGRAPHY.

It has often been observed that the phenomenon of discharge affects electric apparatus in its vicinity. One effect is exceedingly suggestive. Imagine a number of metallic balls placed in a row, just touching each other. Imagine also that the contact is so lightly made that it would not suffice to conduct a current of electricity through the row. A Leyden jar is now discharged in their neighbourhood. It is found that the balls are now making a better contact with each other than before—or a *cohering* effect has been set up. The contact between the balls is now sufficient to conduct a current through the series.

When a Leyden jar is discharged, say, by means of the discharging tongs, the discharge manifests itself as a bright spark. The operation, however, has been found to consist, not in a single rush of electricity from one coating to the other, as might be assumed from the duration of the spark, but in a series of rushes in alternate directions. Assuming the outer coating to be charged with positive, and the inner with negative, there is first a rush from (say) the outer to the inner coating, but equilibrium is not thereby established. The first rush, as it were, overshoots the mark, and leaves the outer coating charged with negative, and the inner with positive. The second stage in the operation then consists of a rush in the reverse direction, again charging the jar as at first, but not to the same extent. These alternations succeed each other with enormous rapidity, each being weaker than its predecessor, until equilibrium is restored, and the jar is discharged. The whole operation lasts but an exceedingly minute portion of time, and is seen only as a single spark. The discharge is thus *oscillatory*.

The operation may be likened to a pail of water held at some height above a pond or river, and suddenly inverted. The falling water, on striking the surface of the river, does not immediately assume the level, but a "splash" ensues, the water rising to some height. The immediate neighbourhood of the surface rises and falls for a sensible *time after the splash is over*. Or, a better analogy is seen in a flat spring, clamped at one end. If this be forcibly bent away from its normal position, and suddenly released, it does not simply return to normal, but *overshoots it, vibrating backwards and forwards* with a gradually decreasing amplitude, until it comes to rest.

The action of which the above are manifestations is the root of "wireless" telegraphy. Wherever a discharge takes place, electric oscillations or waves are set up. These are also termed "Hertzian" waves, from the man whose labours in this field laid the foundation upon which the structure of successful work has been raised. These waves radiate in all directions, the distance to which their effects extend depending on the power expended in setting them up and the sensitiveness of the apparatus for detecting their presence. They are akin to the waves of heat or light in that they *can be reflected, refracted, &c.*, and in that they are propagated in the same medium—the ether of space. Their frequency is of the order of many millions per second, whilst that of light is of the order of hundreds of billions.

Oscillator.—We now come to the apparatus for generating the electric waves. It is essential that the discharge shall be clean and "snappy," not of a brush nature. The usual means of setting up the spark is an induction coil, but Hertz found it necessary to add capacity to the terminals. He did this by using a pair of plates, each carrying a knob or sphere. The terminals of the secondary were attached to these plates, and the spark passed between the knobs. This is the *original oscillator* of Hertz.

Coherer.—The first form of coherer is due to Branly; it has been perfected by Marconi. As seen in Fig. 215 it is a simple glass tube, exhausted of air, containing a pair of silver plugs or stoppers, A A, which fit the tube. These are brought very near each other, their ends being chamfered off as shown. In this very small space a mixture of nickel and silver in a fine state of division or powder is placed, the latter metal being about 5 per cent. of the whole. From the silver stoppers a pair of conducting wires are taken through the ends of the tube. Normally, the arrangement has a very high resistance or is practically non-

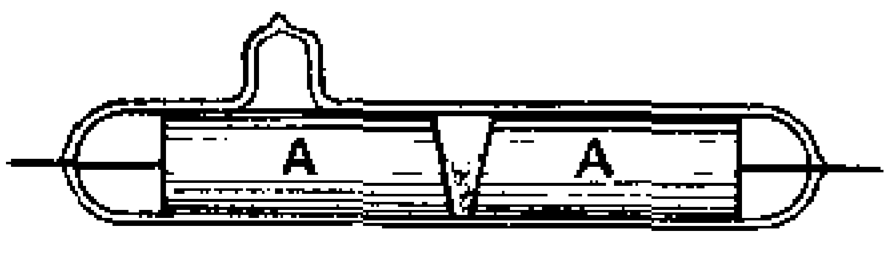


Fig. 215.

conducting, but when the electric waves impinge upon it the metallic powder becomes conductive. It is placed in circuit with a Morse instrument and battery. When conduction has been established the current flows and the receiver is actuated.

This conducting state, however, is permanent, if the tube remains undisturbed, and thus results in a permanent current through the receiving instrument. In order, therefore, to restore the coherer to its original non-conducting state, an electro-magnet whose armature carries a small hammer is arranged to gently tap the tube. This tapping serves to break down the conducting power of the powder, and the coherer is then ready to receive a fresh signal. This electro-magnet is the "tapper-back."

Lodge-Muirhead Coherer.—In this a small steel disc, X, is revolved continuously, the lower portion of its edge touching the surface of a small quantity of mercury, Y, held in a suitable supporting vessel as shown in Fig. 216. On the top of the mercury is a layer of paraffin oil which intervenes between the edge of the disc and the surface of the mercury, thus preventing electrical contact between them. When electric waves are received, the film of oil is broken through and contact established. As soon as the waves cease, the oil again breaks the circuit. The instrument is thus self-restoring. A siphon recorder is used with the coherer—the dots and dashes being formed by the movements of the siphon to one side only of zero.

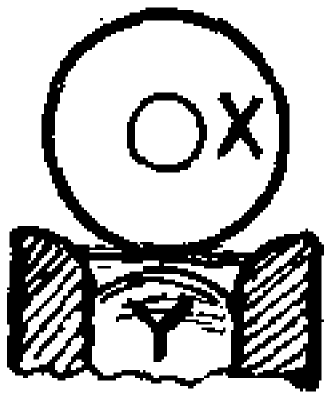


Fig. 216.

Magnetic Detector (Fig. 217).—This is another means for detecting the presence of electric waves. Round a pair of revolving pulleys, P P, an endless band of stranded soft iron wire is passed, the upper part going through a length of glass tube, C C, over which a coil of wire is wound. As a certain portion of the band enters the tube it is acted on inductively by the S pole of one magnet. Passing on it comes to the neighbourhood of the two N poles with a consequent reversal of its magnetism. On leaving the tube it encounters the second S pole and has its magnetism again reversed. The changes in the magnetic state of the iron lag behind the inducing cause—that is, the change produced by passing from an N to an S pole is not immediate and complete on its arrival before the poles. This is the effect known as hysteresis. If, however, electric waves pass through the coil C C, which is in circuit between the aerial and the earth, this hysteresis effect is destroyed and the

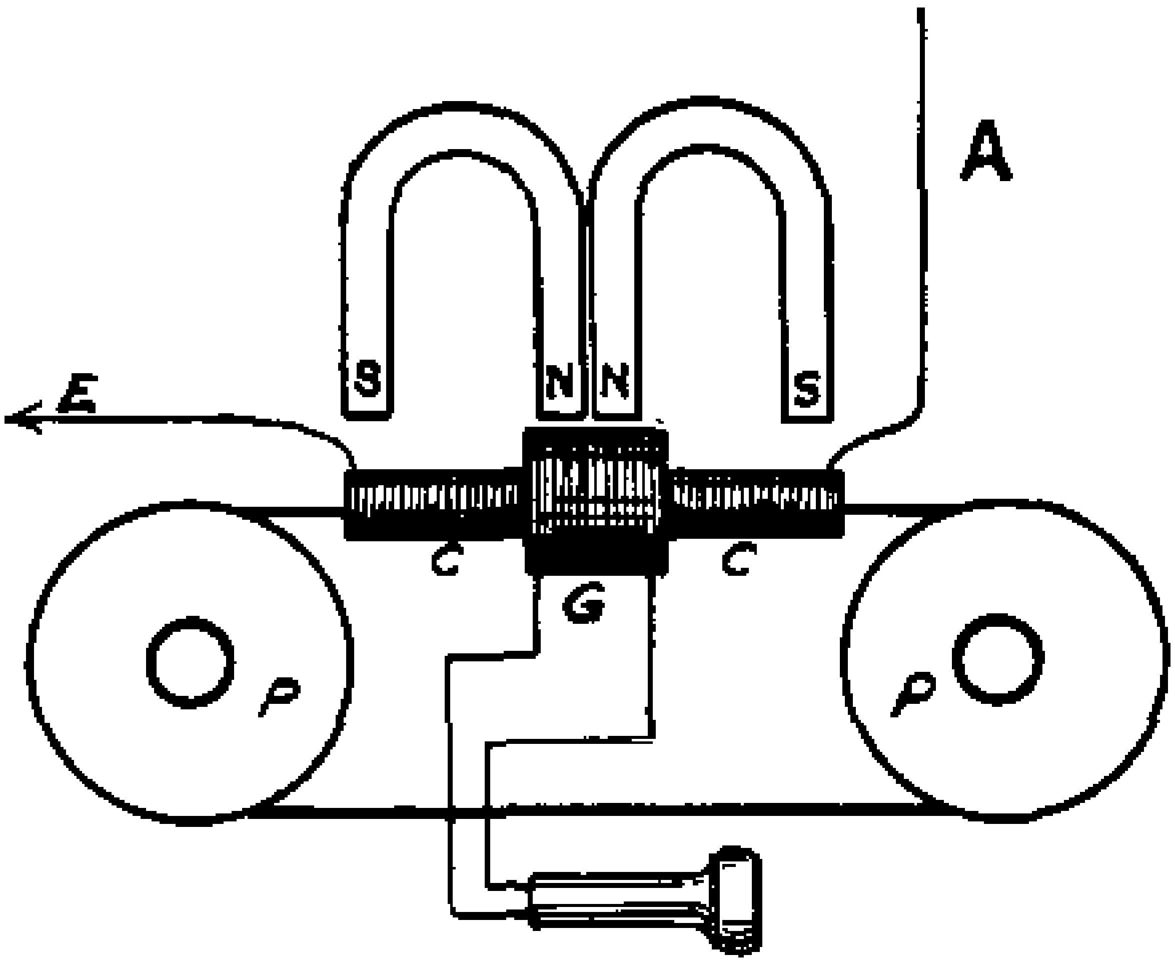


Fig. 217.

iron takes up the changes of magnetism very rapidly. These rapid changes set up currents in the coil G placed over C, and

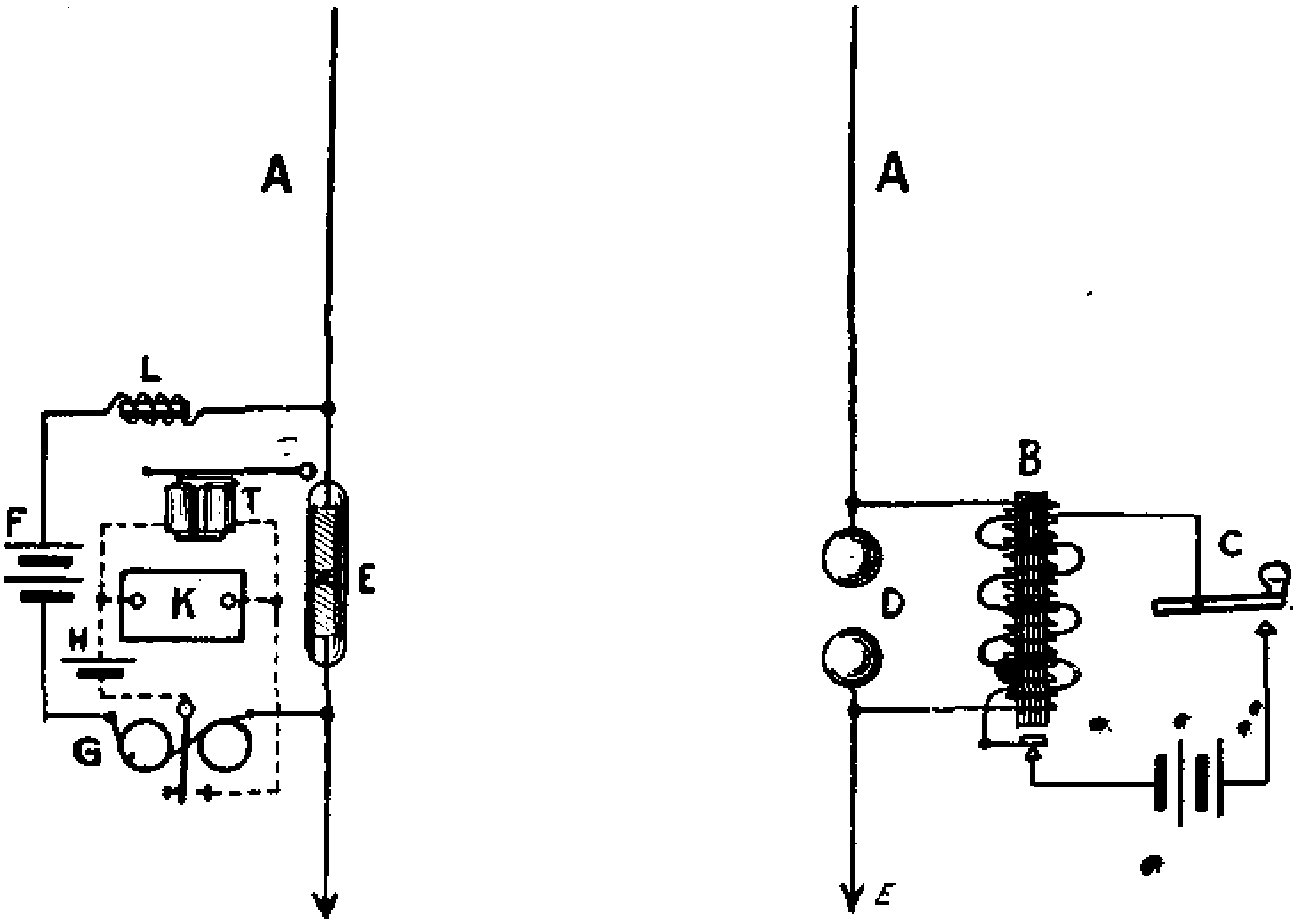


Fig. 218.

these currents are heard in the telephone receiver and signals thus read.

Simple Installation.—We can now consider a simple installation, as in Fig. 218. The capacity plates of the Hertz oscillator are replaced by the aerial and the earth, the former consisting of a tall metallic rod, A. B is an induction coil, whose secondary winding is connected to the balls of the spark-gap D. Its primary includes the key C in addition to its ordinary equipment. The coil, therefore, is not active until the key is depressed. As long as the key is held down a rapid succession of sparks passes between the balls, and trains of waves are sent out from the aerial in all directions. When a dot is signalled a train of a certain length is sent out, whilst for a dash the train is longer continued.

At the receiving station, on the left of Fig. 218, the waves set up coherence in the coherer E thus rendering it conductive. The circuit of the battery F is completed, and the tongue of the relay G moves to marking. H is a local battery and K the receiving instrument, usually a Morse inker. The tapper-back taps the coherer, breaking the circuit, and makes it ready to receive a fresh signal. In order that the tapper may not have too sharp an action upon the signals an inductance coil is included, so as to slow down the action. When a long-continued train of waves, representing a dash, is being received this prevents the breaking of the signal on the relay and recorder.

Oscillation Transformer.—The energy of signalling depends on that imparted to the aerial, and upon this depends to a large extent the distance of practicable signalling—the greater the energy radiated, the greater the distance possible. This depends on the energy of the spark discharge—a longer spark meaning greater energy imparted. But the sparking limit is soon reached, beyond this the spark loses its oscillatory character. Practice in this direction has led to the employment of a special transformer—an "oscillation transformer"—without iron, and consisting simply of a few turns of stout conductor, so arranged that the primary and secondary can be brought into more or less intimate relationship, and thus furnish a strong or weak "coupling" between the two windings. This latter is of great importance in tuning, or in the attainment of syntony. The transmitting arrangements are then separated into two distinct circuits, linked or coupled by this oscillation transformer. A station thus arranged is shown on the right of Fig. 219. The two balls of the spark-gap D are now bridged by the primary of this coil in series with a condenser. The secondary is earthed on one side, and connected to the aerial. By varying the ratio of transformation we are now enabled to communicate much greater energy to the aerial to be radiated.

But these two circuits require to be "in tune" with each other, or the electrical time-period of the two must be the same. That is, the product of the inductance and the capacity of the one must be equal to a similar product of the other. The aerial, itself, is not a simple rod, but a series of wires suspended in

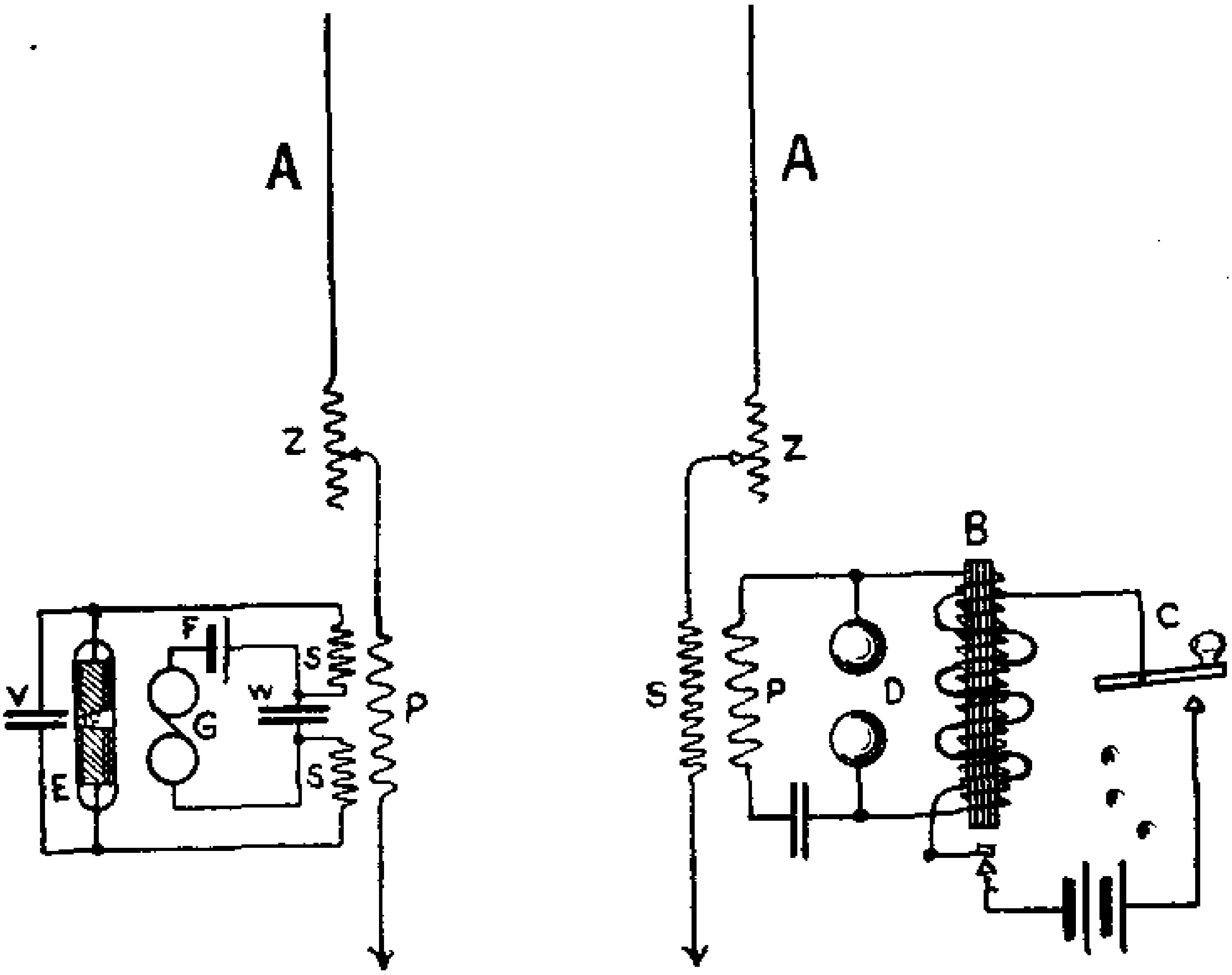


Fig. 219.

the air by means of masts or towers. The coil Z is a simple adjustable inductance (coreless).

Syntony.—Hertz's original receiver or detector was a simple incomplete ring of stout brass rod, its ends terminating in brass spheres, whose distance apart could be adjusted. When a spark passed at the oscillator, a spark also passed between the knobs of the receiver, by the action of the electric waves set up.

To get the maximum effect on the receiver it was necessary to add capacity to it, just as in the case of the oscillator. The former, indeed, had to be "in tune" with the latter in order to get the maximum effect. This is the root of "syntony"—or similarity between the sending and receiving systems—the product of the capacity, and inductance of the one has to be equal to a similar product of the other, as we have already seen. For this reason Hertz termed his receiver a "resonator." A common analogy is seen in the case of two tuning forks. If one be struck, and held in the neighbourhood of another of similar note, the latter will be set into vibration. The same effect is seen when a singer is emitting a certain note. A globe or a wine-glass, whose natural rate of vibration happens to be the same, is thrown into sympathetic vibration, which may be so violent as to shiver the glass.

This syntonic or tuning effect is of the greatest importance. With the arrangements shown in Fig. 218, the waves from the sending station are radiated in all directions. Any number of stations, arranged like that on the left, may then pick up the waves and read. This may be an advantage, but is generally otherwise—anyhow, secrecy between two stations is impossible on such a plan. It is, therefore, sought to arrange that the receiving station shall be sensitive or responsive to one electrical "note," and to be unaffected by any other. We have already described the arrangements at sending station of Fig. 219, and that the two circuits of which it consists are in tune with each other.

At the receiving station on the left, two circuits are similarly arranged. An oscillation transformer has its primary connected to the aerial and earth. The coherer, in series with the relay and battery as in Fig. 218, is in circuit with the secondary. The two circuits are then tuned to each other, and to the sending station. The secondary at the receiving office, as will be seen, is in halves, a condenser being inserted between them. Across the coherer, also, is a condenser. The coherer, as such, is susceptible to any waves, and is, therefore, incapable of tuning. By this arrangement, however, it is sought to render the receiving apparatus sensitive to the waves, from its own sending station only.

Use of the Earth.—Up to the present we have considered the aerial as being to earth, either through the spark-gap, as in Fig. 218, or through the oscillation transformer, as in Fig. 219., Certain advantages are claimed for dispensing with the earth and substituting therefor a considerable capacity—consisting of a large area of metallic netting, insulated from the earth.

Poulsen's Arc.—The oscillations set up by a spark discharge are not persistent, but decrease rapidly in amplitude and die away, or are quickly damped out, whereas it is desirable that they should be continuous and undamped. They may be compared with the sound produced by the repeated plucking of a string, whilst the sound desired should be sustained, as in the case of an organ pipe. Means have, therefore, been sought by which the rapidly-damped spark oscillations might be replaced by a continuous, undamped train of waves. The means have been found in Poulsen's arc. It has been known for some time that if an arc, fed by a direct current, is shunted by a capacity and inductance of suitable value, the arc gives out a musical note, and in the shunt circuit an alternating current is set up of the same frequency. This frequency, however, was much too low for the purposes of wireless telegraphy, but by placing the arc in an atmosphere of coal gas or hydrogen, Poulsen was able to raise the frequency to a suitable value.

The arc is enclosed in a marble box and the gas fed in continuously as the latter is affected by the burning arc. An electro-magnet is also used to set up a magnetic field at right angles to the arc, and this has the effect of steadying it. One of the electrodes (the cathode) is of carbon, and is kept in slow rotation so as to ensure a clean edge; whilst the anode is a copper tube through which water is circulated in order to cool it.

One method of connecting up is to bring one end of the inductance to the aerial by means of the sending key, the other end being to earth. To the back contact of the key is brought an artificial circuit resembling the aerial as nearly as possible so that the conditions at the sending end shall not be varied by the movements of the key. The arc is thus kept steadily at work, but the aerial is connected up and radiations sent out only when the key is depressed.

Skegness-Hunstanton Installation.—By this means communication is established across the Wash between the Lincolnshire and Norfolk coasts. The aerial system is indicated in Fig. 220, and consists of six wires suspended from a wooden spreader at the top of a built-up mast of wood some 120 feet high. Near the top a cross wire connects them together, whilst they are kept apart by insulating stays near the bottom. The lower ends are connected together in two groups of three wires each, and led into the interior of the station. Inside is an ebonite ring, Z, with three set screws whose ends nearly meet at the centre of the ring. To two of these the two groups of the aerial are brought.

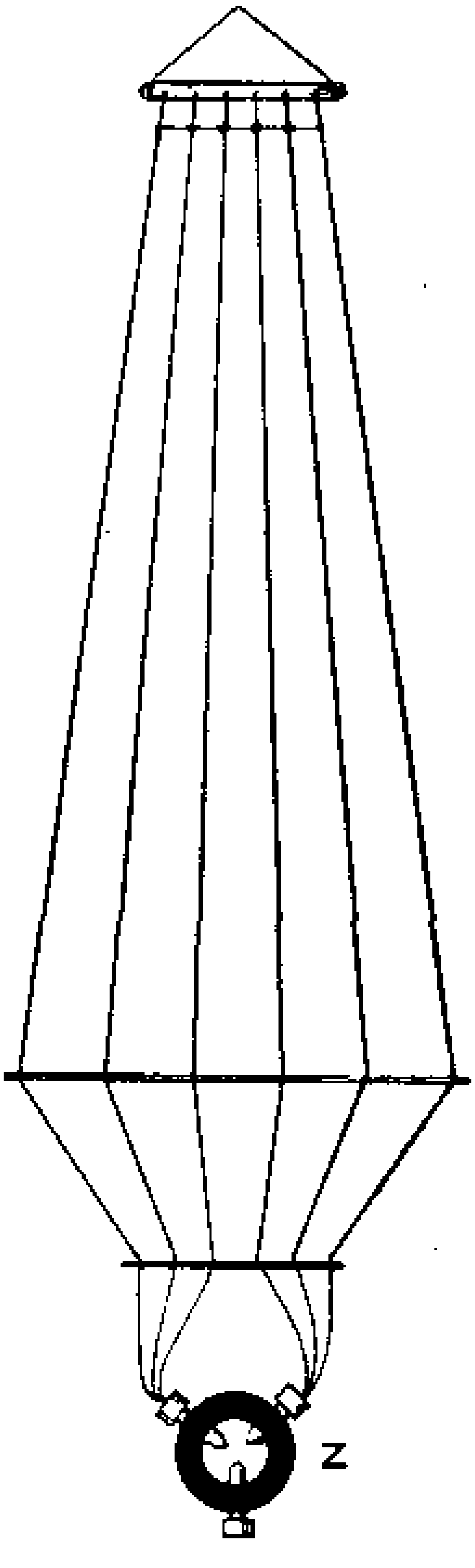


Fig. 220.

The connections for receiving are given in Fig. 221, and those for sending in Fig. 222. In the latter a small alternator, X, driven by an oil engine, is connected to the primary circuit of a transformer, but no current passes until the sending key C is depressed. The secondary sends into the oscillatory circuit, made up of the condenser K—a group of Leyden jars—a portion of the auto-transformer O and the spark-gap D. One end of O and one side of the gap are earthed. Another portion of O is connected to the third screw of the ebonite ring before-mentioned. O is thus an oscillation transformer consisting of a single coil (without iron), the portion *a* to *b* being in circuit with the aerial and the portion *b*, E, being in the oscillation circuit. The two points *a*, *b*, are adjustable. When the key is depressed, sparks pass across the gap D, and the signals sent out also spark across from the lower screw of Z to those connected with the aerial.

The alternator, oil engine, &c., are accommodated in an outer shed at each station in order to shut off from the operating room any noise or vibration. The two condensers in the alternator leads are to protect the coils of the latter from any sparking which might be caused by the high frequency alternations entering the leads. The transformer takes about 9 amperes at 110 volts and a frequency of 40 periods and transforms it up to about 20,000 volts. An adjustable resistance (not shown) is also included in the power circuit in order that the power used may be regulated. The spark-gap is enclosed in a mica cylinder and is placed inside the inductance O.

The receiving connections are shown in Fig. 221. The tuning box contains the two inductance coils U and Q and the capacity M. By this means each half of the aerial can be syntonized separately. The received oscillations pass through the coils U and Q to earth, exciting similar movements in the oscillation circuit containing the electrolytic detector Y. The latter is a small glass cell containing a solution of a metallic salt. Into this dips a glass tube having a fine platinum point fused into it. As will be seen from Fig. 221, current from the battery F is continually passing through this electrolytic cell and a telephone receiver, R. By means of the resistance P the voltage actually applied can be varied. When the electric waves pass, the conductivity of the cell is varied, and this gives rise to changes in the value of the current passing. The changes are sufficiently rapid to affect the telephone by which the signals are read.

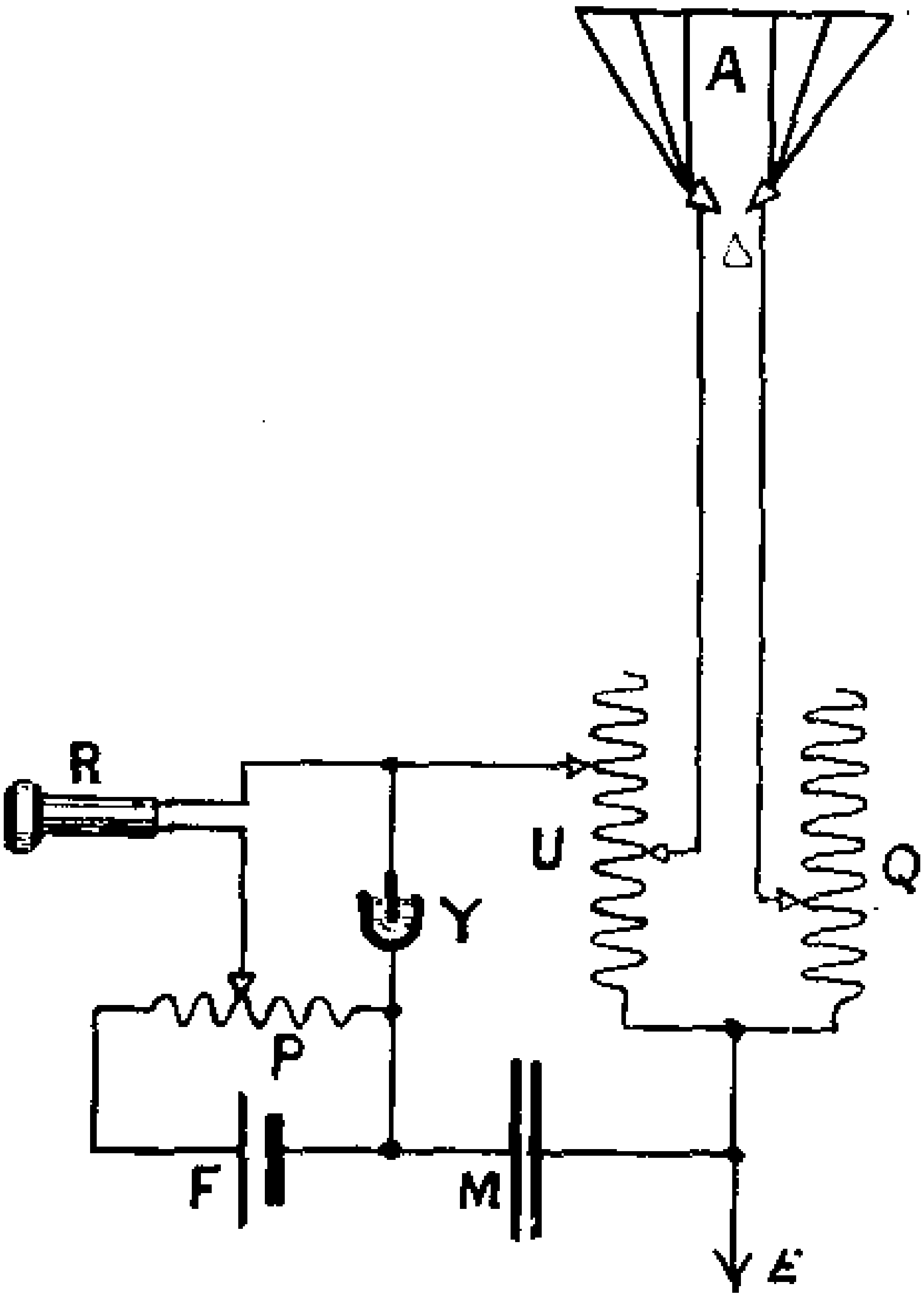


Fig. 221.

By means of a switch a Maskelyne "conjunctor" can be substituted for the electrolytic receiver. This acts in a precisely similar manner to a coherer, and is de-cohered by a vibrator.

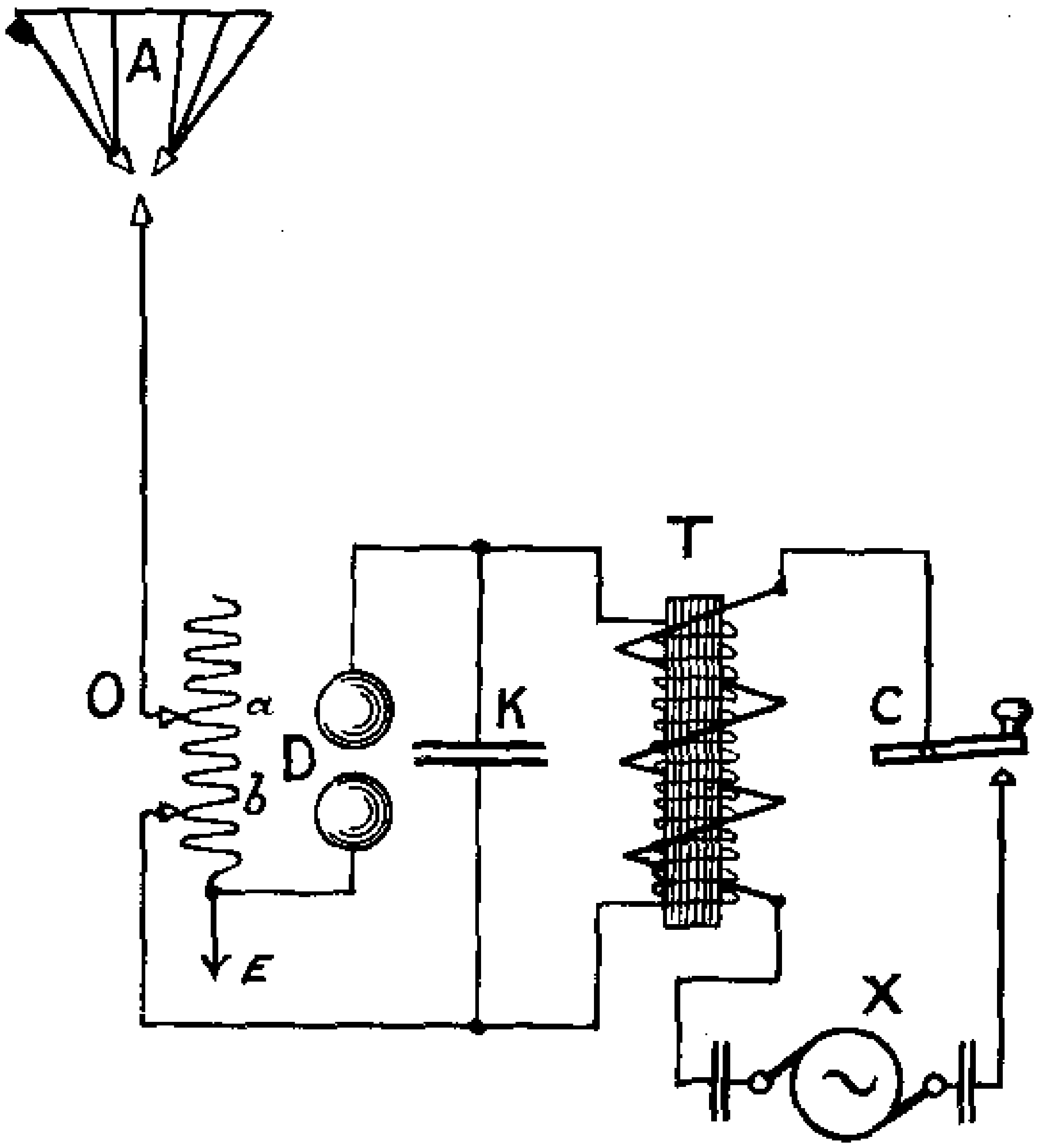


Fig. 222.

It actuates a delicate moving-coil relay in whose local circuit a Morse inker is placed. This is used for receiving calls. The clockwork is started by the received signal, and when these cease the inker automatically stops.

INDEX.

⁂ On p. 268 an Index to the diagrams of connection will be found.

A

ACCUMULATORS, 10.
Additional increment, Quadruplex, 77.
Agglomerate Leclanché, 8.
Amalgamation, 2.
Artificial circuit, Muirhead's, 247.
Automatic, 81.
  ,, cable working, 241.
  ,, duplex, 103.
  ,, switch, 201.

B

BAUDOT, 132.
  ,, alphabet, 135.
  ,, distributor, 146.
"Bias" of relay, 42.
Bichromate cell, 9.
Brown's relay (submarine), 249.

C

CABLE repeaters, 249.
Callaud cell, 5.
Capacity in compensation circuit, 40.
Central battery duplex, 193.
  ,, system, 192.
Coherer, 254.
Comparison, Bridge and differential duplex, 46.
Concentrator: equalising resistances, 184.
  ,, mixed single and double-current, 185.
  ,, switches, 181.
  ,, up and down circuits, 184.
Creed keyboard perforator, 88.
  ,, receiving perforator, 99.
Curbing, 240.

D

DANIELL cell, 1.
Decrement system, 65.
Diagrams of connections (see p. 268).
Differential galvanometer, 41.
  ,, winding, 35.
Difficulties peculiar to submarine telegraphy, 235.
Diplex repeater, 221.
  ,, working, 58.
Double-current repeater, 201.
Dry cell, 9.
Duplex: balancing, 41.
  ,, Bridge, 48.
  ,, Differential, 34.
  ,, Double-current, 45.
  ,, Effect of battery-resistance, 37.
  ,, magnetic bridge, 56.
  ,, multiplex, 111.
  ,, repeater, 198.
Duplexing of cables, 246.

E

EFFECT of electric discharge, 253.
Electro-magnetic switch, 201.
E.M.F. of secondary cell, 15.
E.P.S. cells, 13.
Essentials of battery for telegraphic use, 1.
Evolution of repeater, 195.

F

FAST speed repeater, 211.
Forked news repeater, 213.
  ,, quadruplex repeater, 223.
Forming of accumulator plates, 11.
Fuller's bichromate cell, 9.

G

Gravity cells, 5.

H

Hart accumulators, 12.
Hertzian waves, 254.
Hughes duplex, 130.
  ,, instrument, 114.
  ,, repeater, cable discharge, 205.
  ,, repeaters, 203.

I

Incrementer, 220.
Incrementing voltages, 80.
Instrument-room cabinet, 180.
Interaction of A and B keys, 87.

K

Kotyra keyboard, 88.

L

Leclanché cell, 6.
Local action, 2.
Lodge-Muirhead coherer, 255.

M

Magnetic detector, 255.
Meidinger cell, 6.
Metal-cased resistance coils, 23.
Metropolitan intercommunication, 186.
Minotto cell, 5.
Mirror galvanometer, 237.
Muirhead relay, 252
Muirhead's artificial circuit, 247.
Multiplex, 104.
  ,, correcting currents, 109.
  ,, distributor, 106.
  ,, motor and reed, 107.
Murray alphabet, 153.
  ,, -Creed printer, *100.*
  ,, perforator, 151.
  ,, printer, 163.
Murray receiving apparatus, 161.
  ,, recorder, 159.
  ,, system, 150.
  ,, ,, governing, 163.
  ,, ,, *obliteration of errors, 153.*
  ,, transmitter, 155.

N

Night and Sunday *concentration,* 183.
Non-polarized standard relay, 60.

O

Oscillations, Undamped, 260.
Oscillation transformer, 257.
Oscillator, 254.

P

Pasting of accumulator plates, 11.
Perforator, 81.
Phonic wheel, 108, 157.
Pneumatic perforator, 86.
Polarized standard relay, 41.
Pole-changer, 219.
Poulsen's arc, 260.
Primary and secondary cells, compared, 10.
  ,, cells, 1.

Q

Quadruplex, 67.
  ,, analysis of key positions, 68.
  ,, A side relayed, 228.
  ,, automatic on A side, 77.
  ,, automatic working, additional increment for, 77.
  ,, decrement working, 80.
  ,, effect of mid-position of key, 72.
  ,, local circuit of B relay, 6[illegible]
  ,, *old form,* [illegible]4.

Quadruplex repeaters, 219.
  ,, simplification of B local circuit, 75.
  ,, skeleton connections, 73.
  ,, standard arrangement, 74.

R

Reflecting galvanometer, 237.
Relation between test-board and instrument tables, 177.
Relaying sounder, 63.
Relay, Standard non-polarized, 60.
  ,, Standard polarized, 41.
Repeater, Diplex, 221.
  ,, Double-current, 201.
  ,, Duplexing of, 198.
  ,, Evolution of, 195.
  ,, Fast speed, 211.
  ,, Forked news, 213.
  ,, Forked quadruplex, 223.
  for submarine cables, 249.
  ,, Hughes, 203.
  ,, Quadruplex, 222.
  ,, Simple, 197.
  ,, Split quadruplex, 225.
  ,, test and battery-box connections, 233.
Repeaters, 195.
Resistance coils, Metal-cased, 23.
[illegible]rdation, 111.
Rheo[illegible]at, 38.

S

Screw-terminal test-box, 171.
Secondary cells, 10.
  ,, effects of charge and discharge, 15.
Shape of signals, 96.
S[illegible]rt-circuiting at keys, quadruplex, [illegible]2.
Shunted condenser, 95.
Siemens and Halske cell, 4.
Simple repeater, 197.
Siphon recorder, 239.
Skegness-Hunstanton wireless installation, 260.
Slip, perforated and received (submarine), 241.
Sounder silencer, 228.
Specific gravity, secondary cell, 15.
Split quadruplex repeater, 225.
Splitting of B marks, quadruplex, 63.
Standard non-polarized relay, 60.
  ,, polarized relay, 41.
Submarine, 235.
Switch-spring test-board, 174.
Synchronism and isochronism, 106.
Syntony, 258.

T

Table cases, 180.
Tapper-back, 255.
Test and battery boxes, 171.
Test-box detector, 173.
Test-hole and U-link test-box, 172.
Transmitter, Automatic curb, 242.
Triple condenser, 39.
Trough Daniell cell, 3.
Tuning, 259.

U

Universal batteries—
  a double set necessary, 17.
  advantages of, 16.
  arrangement of voltages, 18.
  connections for, 19.
  system of grouping, 16.
  use of primaries, 17.
  use of secondaries, 18.

W

Wheatstone perforator, 82.
  ,, receiver, 93.
  ,, transmitter, 89.
Wireless, 253.
  ,, installation, 257.

DIAGRAMS OF CONNECTIONS.

Note.—The first of two or more references to a similar diagram gives the connections for primary, the rest for secondary batteries.

	FIGS.	PAGES
Automatic,	88, 89	98, 99
Do. duplex or single,	90, 91	100, 101
Do. duplex (bridge) or single,	92	102
Baudot,	125	148
Central battery, duplex or single,	163	193
Diplex or single,	62	66
Double-current,	26-30	28-31
Do. duplex or single,	44, 45	48, 49
Do. duplex (bridge) or single,	55	57
Double sounder,	19, 20, 21	22-24
Hughes,	108	127
Do. duplex or single,	110	129
Do. duplex (bridge) or single,	109	128
Multiplex,	97	110
Murray,	144	169
Quadruplex, A side relayed,	191	227
Do. old form,	69	74
Do. standard arrangement,	70, 71	75, 76
Do. Wheatstone A side,	72, 73	78, 79
Repeater, fast speed, duplex or single,	178	214
Do. forked news,	181	218
Do. do. quadruplex,	189	224
Do. Hughes,	170	204
Do. do. duplex or single,	173	208
Do. quadruplex or single,	187	222
Do. split quadruplex,	190	226
Single-current, duplex or single,	39	44
Do. with relay,	22-25	25-27
Single needle,	16, 17, 18	19-21

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